EXPERIMENTAL INVESTIGATION INTO SURFACE CHARACTERISTICS OF WORK PIECE DURING PLASMA HOT MACHINING OF En-24 STEEL

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to the

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3/5/84

CERTIFICATE

This is to certify that this work on "EXPERIMENTAL INVESTIGATION INTO SURFACE CHARACTERISTICS OF WORK PIECE DURING PLASMA HOT MACHINING OF EN-24 STEEL" by H.M. Viswananda has been carried out under my supervision and that this has not been submitted elsewhere for a degree.

G S Kainth 3/5/84

May, 1984.

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SYNOPSIS

This report presents experimental investigation on Hot Machining of En-24 steel with Coromant carbide tips using plasma arc heating. A comparison of Plasma Hot Machining with Conventional Machining is made.

A three dimensional lathe tool dynamometer is designed and fabricated to study the variation of cutting forces. Experiments are conducted for compartive study of tool chip interface temperature and surface integrity obtained during Conventional Machining and Plasma Hot Machining . The machining is performed with speeds ranging from 52 m/min to 166 m/min at a constant feed and depth of cut of 0.15 mm/rev and 1 mm respectively. Throw away carbide tipped tool having geometry 0, 6, 11, 5, 15, 15, 1.2 is used. Fresh cutting edge is used for each experiment. Plasma Hot Machining experiments are conducted using a 2.75 KVA micro plasma welding unit (Indian Oxygen Company) with optimal parameters, viz., arc current of 15 amps, Argon gas pressure of 6 kg/cm^2, and gas flow rate of 3 litres/min . To study the effect of stand -off distance, machining tests are conducted with stand-off distances 4, 6, 8 and 10 mm for 52 m/min and 105 m/min speed.

Tool chip interface temperature is measured using tool chip thermocouple principle. NU-2 microscope with microhardness

testing attachment is used to measure microhardness. Profilometer (Bendix Corporation, U.S.A.) is used to measure surface finish.

The behaviour of cutting forces, tool chip interface temperature, surface finish and microhardness with cutting speed and stand-off distance are presented .

Following conclusions are drawn :-

(1) The cutting forces reduce during Plasma Hot Machining compared to conventional Machining.

(2) Tool chip interface temperature increases during Plasma Hot Machining.

(3) Surface finish improves due to Plasma Hot Machining.

(4) Increase in surface hardness is more in the case of Plasma Hot Machining compared to Conventional Machining.

CHAPTER 1

INTRODUCTION AND LITERATURE SURVEY

1.1 General

Low metal removal rate obtained during Conventional Machining of High Strength Temperature Resistant (HSTR) and refractory materials has created a demand for improved methods of metal removal. Hot Machining is one of the most promising process being applied to machine these materials. The basic idea behind Hot Machining is to raise the temperature of the workpiece, just ahead of cutting tool close to recrystalisation temperature to reduce the shear strength in the immediate vicinity of the shear plane. Toughness and hardness primarily determine the machining characteristic of materials. These properties are temperature dependant. So the application and control of heat in the region of metal deformation forms the basis of Hot Machining.

The selection of suitable heating method depends on the type of machining operation, thermal efficiency and the extent of thermal damage.

The main requirements of a suitable heating technique are:

a) Heating should be intense and confined to the shear-zone .

b) The time lapse between heat application and cutting should be small so that minimum heat is soaked into the workpiece to avoid metallurgical damage.

c) It should be economical both in installation and operation.

The various heating methods (1,2) used for Hot Machining are: Electric resistance heating , Induction heating, Oxy-acetylene gas heating, Electric arc heating and Plasma arc heating.

The Plasma arc heating is used in the present investigation due to its high specific heat input and ease of controlling the heat input to the workpiece.

1.2 Literature Survey

Hot Machining has been under investigation for many years as a method for improving machinability of metals that are otherwise difficult to machine [1, 3, 4]

Tour and Fletcher[3] showed that a substantial increase in metal removal rate can be obtained by Hot Machining using induction and oxy-acetylene gas heating technique. Localised heating of the workpiece, just ahead of the point of machining results in improved machinability, reduced power consumption good part finish and increased tool life. Figure. 1 shows the

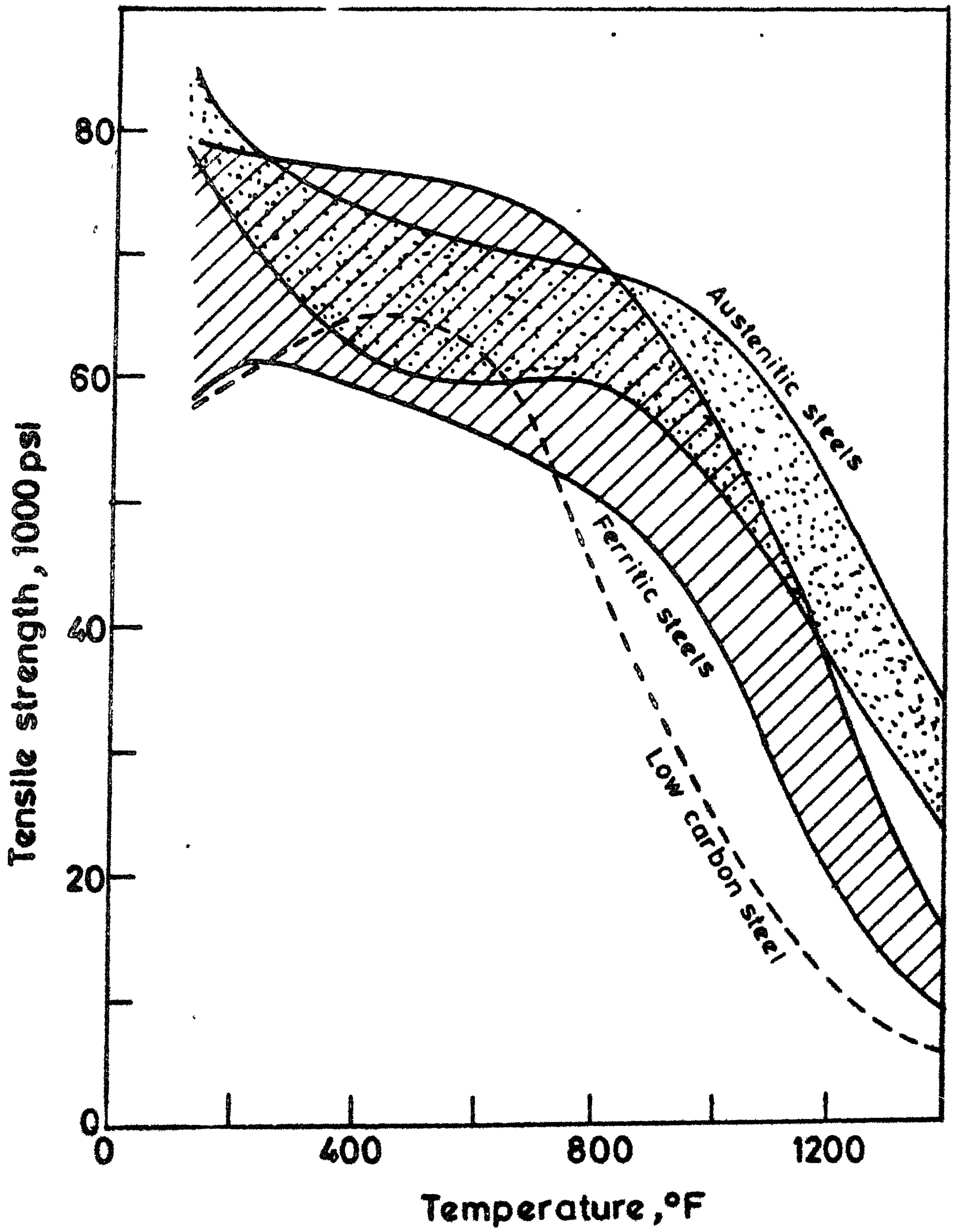


FIG.1 INFLUENCE OF TEMPERATURE ON TENSILE STRENGTH
[After Tour and Fletcher (1)]

variation in strength with temperature for various steels investigated by them. It is found that heating mild steel to a temperature of 1500 °F increases the metal removal rate by 300% . In the case of heat treated alloy steel having a tensile strength of 120,000 psi and cobalt chromium steels, the metal removal rate increases by 200% and 125% respectively.

Schmidt[4], using oxy-acetylene gas heating, showed that the power required for machining high strength alloys at elevated temperature is considerably less than that required for machining at room temperature.

Armstrong, Cosler and Katz [5] found that tool life increased ten fold when cutting austenitic stainless steel at 400 °F . High temperature alloys eg. vitallium could be machined freely at temperatures ranging from 700 °F to 2000 °F. It was observed that long curling chips and smooth surfaces were produced in Hot Machining using induction and arc heating . The same materials when cut at room temperature produced powdery chips and a glazed uneven surface.

Krabacher and Merchant [6] using oxy-propane flame heating, showed that tool life does not always increase with increase in workpiece temperature. Instead, for a given work material, there is a definite temperature at which tool life is maximum. Tool life mainly depends on the tool chip interface temperature and abrading action of the work

on the tool. They also found that chip friction reduces with increase in temperature leading to lower tool forces. The main factor responsible for lower tool forces at elevated temperature is the decrease in shear strength of the material.

Hinds and Almeida [2,7] opined that plasma arc heating is the most efficient heating method. Very high workpiece temperatures can be attained within fraction of a second due to high specific heat input capacity of the plasma arc. They investigated the resultant temperature field at the entrance of the cutting zone and studied the optimum positioning of the torch to achieve the greatest benefit. They observed that the efficiency of heat energy transfer to the workpiece reduces with increase in cutting speed and stand-off distance (Fig. 2) . They found that heat transfer is more effective in the range of cutting speeds from 100 to 150 m/min, for a gas flow rate of 4.0 litres/min, voltage of 44 volts, current of 100 amps and a stand-off distance of 9 mm.

Reznikov etal [8] carried out research on temperatures occuring during cutting with plasma pre-heating. They determined cutting forces, cutting rates, tool life and chip contraction during the cutting of alloy steels . They compared the temperature distribution in the cutting zone due to plasma jet heating and electro contact (electric resistance) heating. The temperature fields resulting from

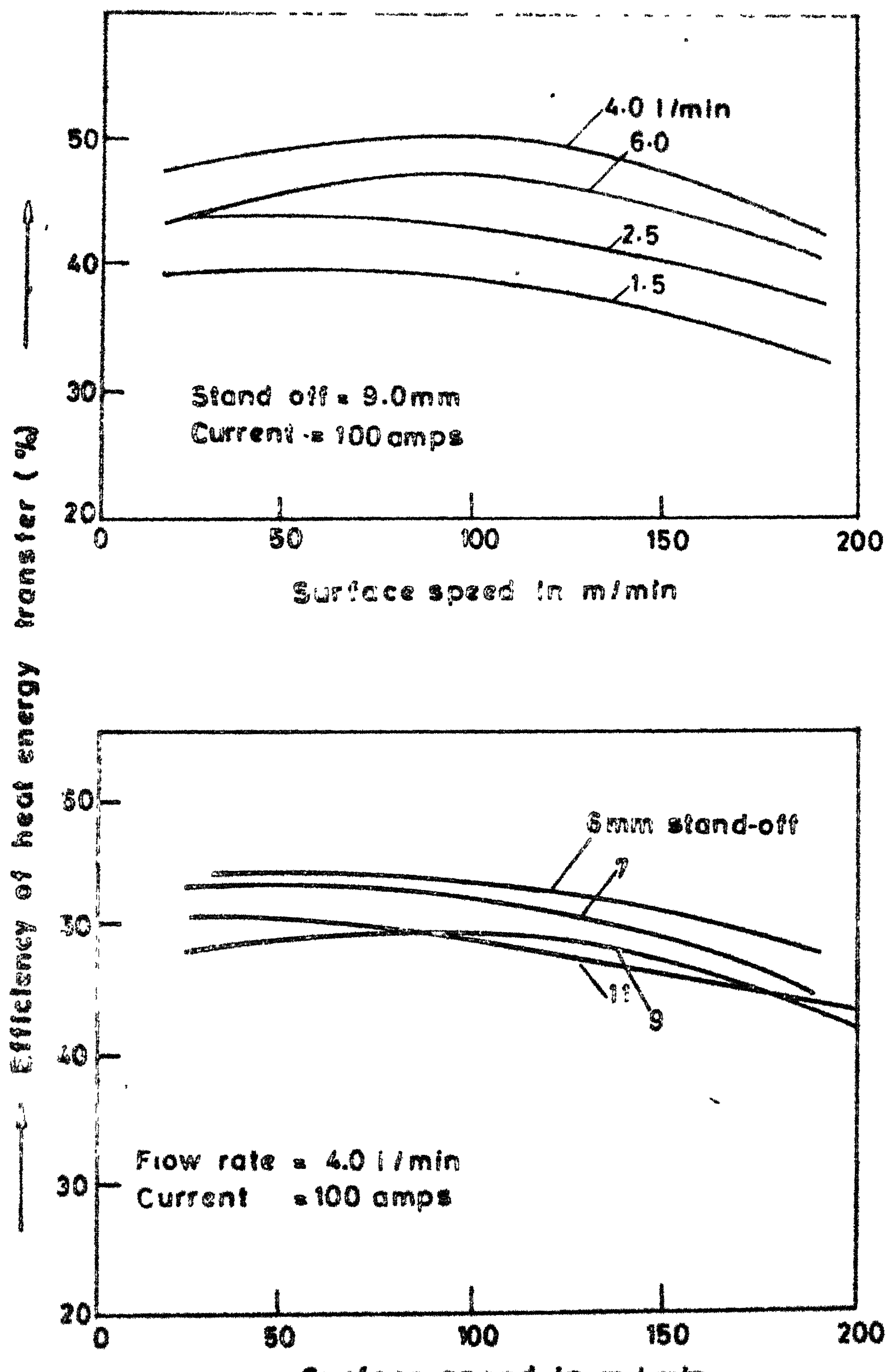
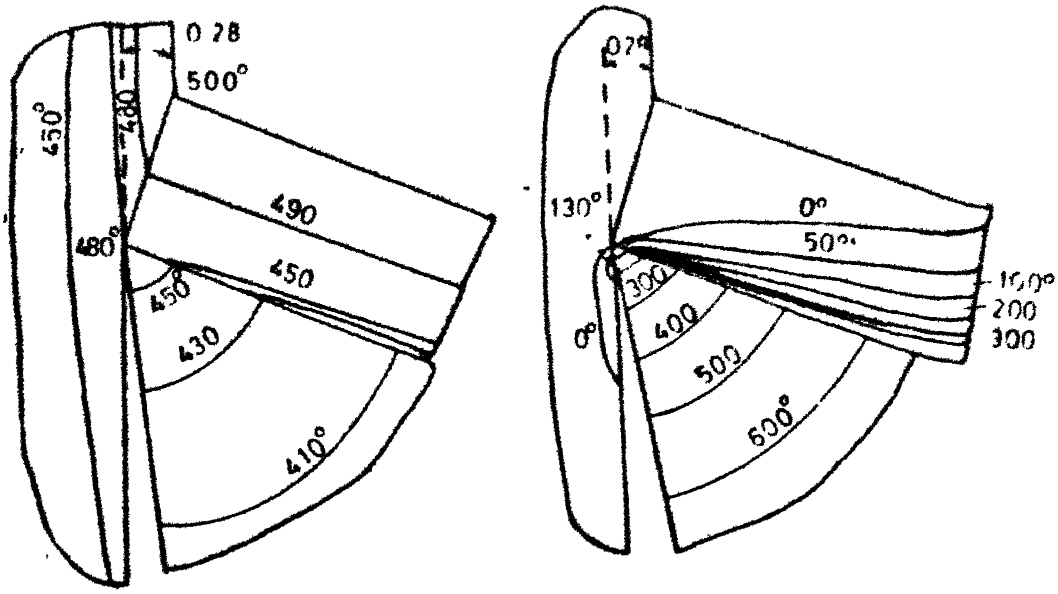


FIG.2 HEAT TRANSFER EFFICIENCY AT DIFFERENT WORK PIECE VELOCITIES (After Hinds and Almeida [6])

additional pre-heating of cutting zone is shown in Fig. 3a. The effect of heating by the ancillary source alone is considered and the heat resulting from cutting is not included. They argued that electro contact pre-heating raises the temperature of only the chip layer adjacent to the tool and that the region of fundamental plastic deformation is not affected. On the other hand, plasma pre-heating of the workpiece in the vicinity of the shear surface causes pre-heating to a fairly high temperature resulting in the reduction of work material strength. This leads to reduced cutting force as shown in Fig. 3b. The increased plasticity of the work material increases the chip contact with the tool which gives rise to more uniform heating of the cutting edge . This results in reduction of stress at the tool tip and more uniform wear of the cutting edge with increased tool life.

1.2.1 Plasma Arc Heating

Plasma arc is in use in the welding industries as a heat source for a long time. Plasma is produced when gases such as Argon, Helium and Hydrogen are passed through an electric arc, the gases dissociate into atoms due to high temperature of the arc. These atoms collide with high velocity electrons which in turn cause ionisation of the gases. The processes of dissociation and ionisation of gases



(1) PLASMA JET HEATING (2) ELECTRO CONTACT HEATING

FIG.3a TEMPERATURE FIELDS RESULTING FROM PREHEAT OF CUTTING ZONE

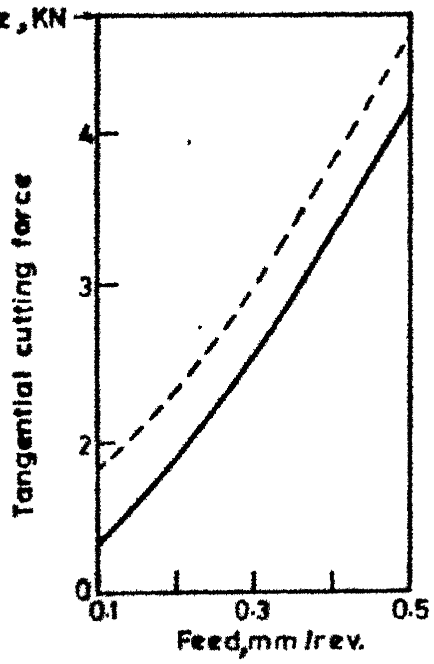


FIG. 3b INFLUENCE OF PLASMA HEATING ON CUTTING FORCE

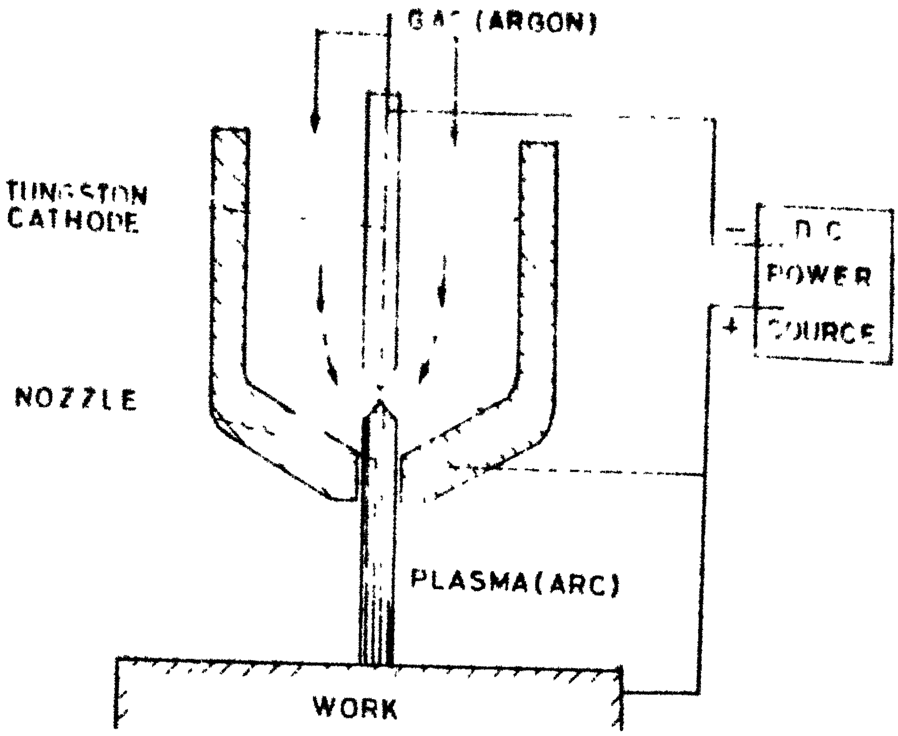
(After Reznikov, et al [8])

are accompanied by absorption of heat.

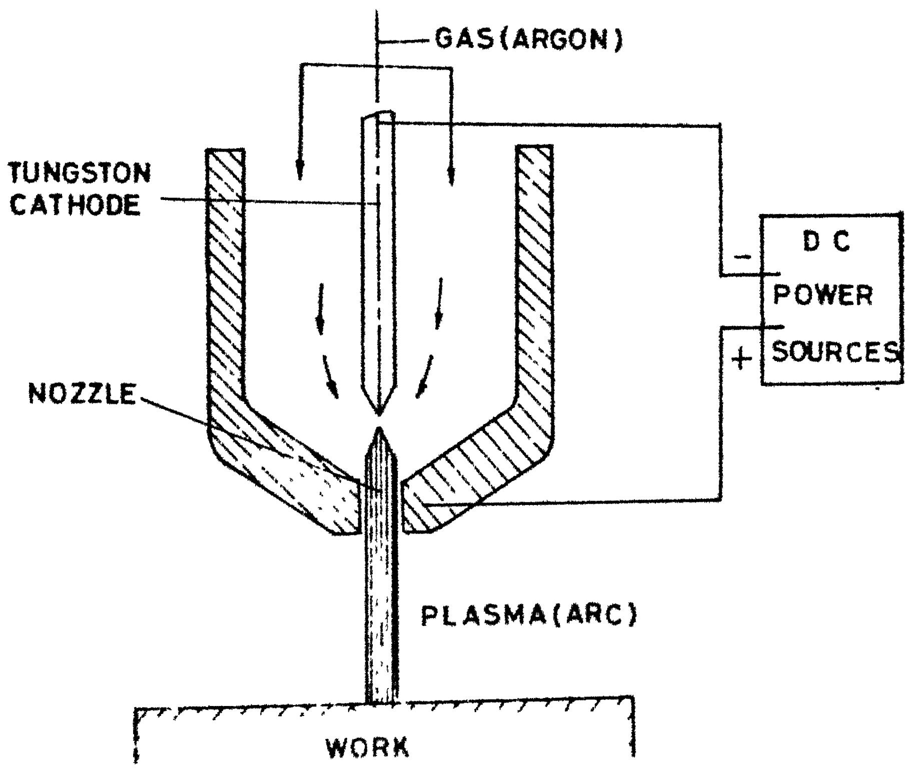
The processes of dissociation and ionisation are carried out in a torch having a tungsten cathode and a brass nozzle which acts as an anode. An arc is struck inside the torch and Argon gas is passed through the arc. A shielding gas is generally used which envelopes the plasma gas and reduces the loss of heat to the environment. Water supply through the torch keeps the temperature of the cathode at low levels.

Plasma arc can be used in two modes viz., (a) transferred arc mode and (b) non-transferred arc mode as shown in Fig. 4. In transferred arc mode the nozzle and work-piece are made anode. Pilot arc is struck between the tungsten cathode and the nozzle. As soon as the main arc is established, work piece acts as anode thereby avoiding heating of the nozzle. Very high current densities can be used in this configuration.

In non-transferred arc mode the nozzle solely acts as an anode. Pilot and the main arc are established between tungsten cathode and the nozzle. The plasma stream in the case of non-transfreed arc mode is electrically neutral. However, the nozzle is subjected to impinging electrons. So it is desirable that the arc be distributed over relatively largerarea of anode rather than a single spot to avoid damage to the nozzle.



(a) TRANSFERRED ARC MODE



(b) NON-TRANSFERRED ARC MODE

FIG 4

Limitations of transferred arc mode :-

(a) The torch is subjected to intense radiation of the arc column.

(b) It cannot be used in the case of electrically non conducting materials.

(c) It is difficult to connect the work piece to the anode of the supply in the case of turning operation.

(d) It requires elaborate instrumentation to measure tool chip interface temperature by using tool work thermocouple due to interference of power supply to the work piece.

In the present investigation non-transferred arc mode is preferred due to the above mentioned limitations of transferred arc mode.

1.2.2 Effect on Surface Integrity

Machining is a mechanically and metallurgically very severe deformation operation which influences the properties of the finished surface.

Turkovich and Field [9] listed major types of surface alterations in machining as :
Plastic deformation, plastically deformed debris, laps, tears and crevice like defects, microcracks, intergranular attack, over tempered and untempered martensite, over aging, recast, respattered metal or vapour deposited metal, microhardness and residual stress.

The major causes of surface alterations are high temperature gradient, plastically deformed debris, chemical reactions and subsequent absorption into the machined surface They found that "depth of surface alterations in most material removal processes are quite shallow', usually under 0.25 mm".

Surface hardening results from the formation of untempered martensite and plastic deformation by cold working.

Mechanical residual stresses are developed due to inhomogenous plastic flow caused by external forces, thermal gradients, glide, twinning, kinking and dislocation etc. Other residual stresses are produced by chemical or structural effects, alloying precipitation and phase transformation etc.

Leskovar and Peklenik [10] experimentally determined the microhardness and residual stresses of the machined surface . They found that microhardness is affected more by wear of the tool rather than the cutting speed (Fig. 5) The studies on metallographic pictures have revealed the indications of deformation of surface layer.

Liu and Barash [11, 12, 13] exhaustively studied the residual stresses developed in the machined surface and its causes. They found that residual stresses of higher value are induced by lower cutting speeds at smaller depth

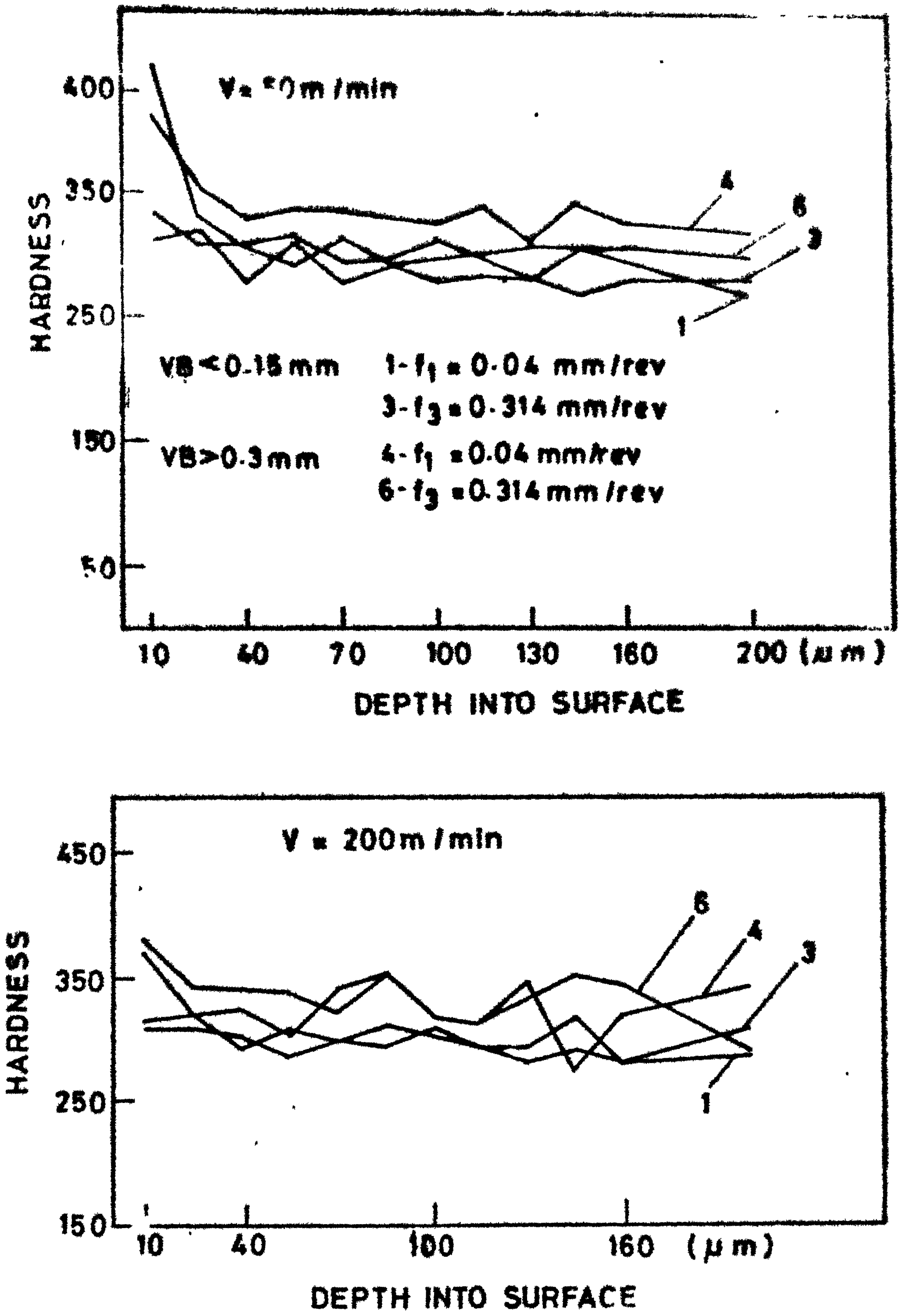


FIG. 5 MICROHARDNESS AS A FUNCTION OF FEED RATE f AND THE TOOL WEAR VB
(After Leskovar and Peklenik [10])

of cuts. Smaller the depth of cut greater is the effect of cutting speed. At slow speeds a smaller depth of cut produces higher tensile stresses. At higher speeds the reverse occurs. The shape of the cutting edge such as edge radius and effective clearance angle will determine the residual stresses in a machined surface. Residual stress distribution along and across the cutting direction in the conventional cutting is shown in Fig. 6.

Ovseenko etal [14] investigated the effect of pre-heating on the machined surface layer of high alloy cast irons. They found that in the case of pre-heating upto 300° C the reduction in cutting temperature as a result of diminished work piece strength, proceeds more intensively than the increase in the temperature as a result of pre-heating. A pre-heating temperature of over 300°C has a more powerful effect on the total temperature than the reduction of cutting temperature. Figure 7a shows the effect of pre-heating temperature on the temperature of the machined surface layer for different cutting speeds. The reduction in surface temperature is more at higher speeds. The compressive residual stresses produced after machining with pre-heating are greater than those produced in machining without pre-heating due to the reduction in surface terperature. The effect of pre-heating on the residual stresses is shown in Fig. 7b.

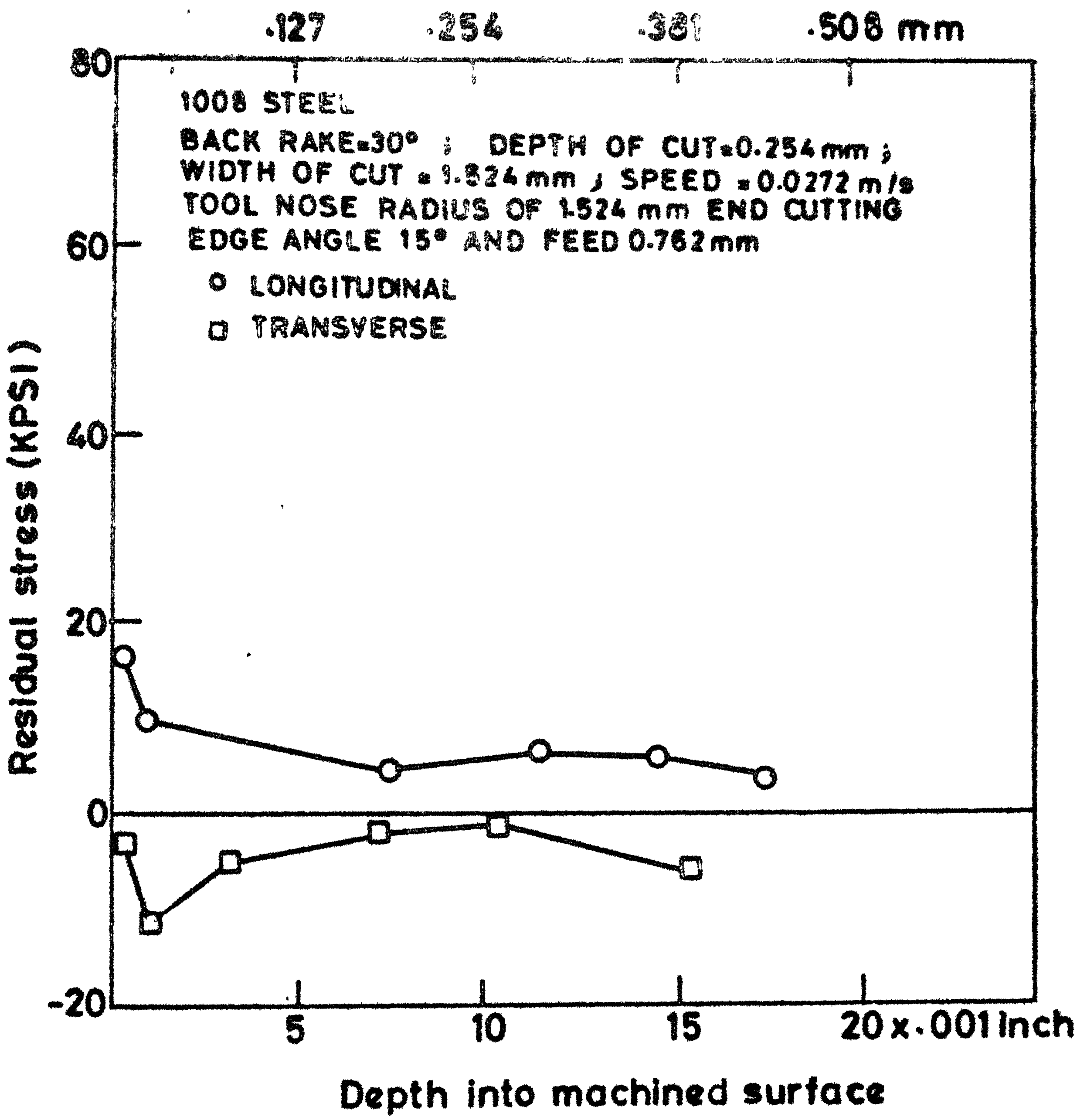
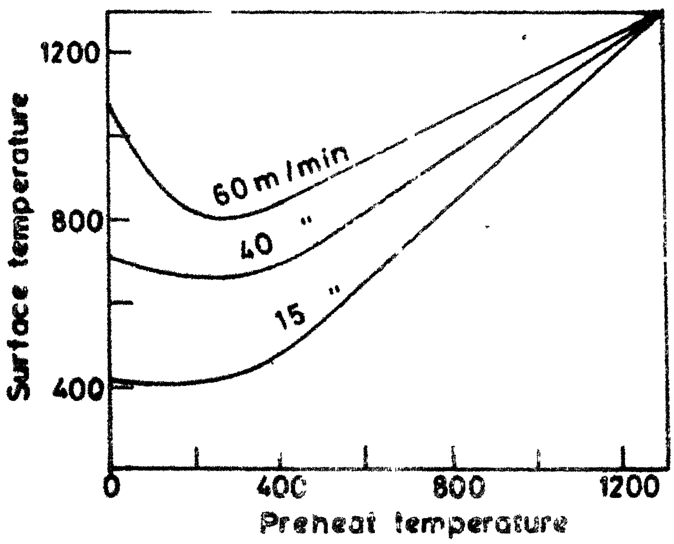
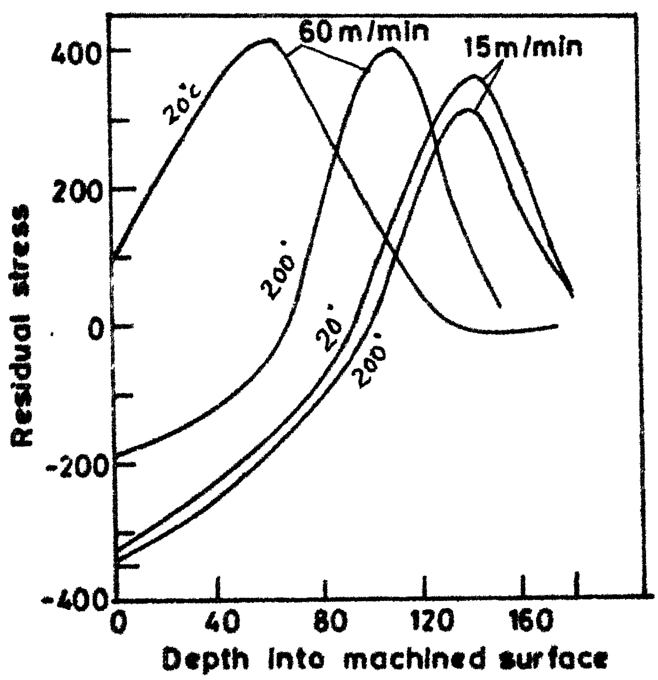


FIG.6 RESIDUAL STRESS IN CONVENTIONAL CUTTING.
(After Liu and Barash [11])



(a)



(b)

FIG.7 EFFECT OF PRE-HEAT TEMPERATURE ON SURFACE TEMP. AND RESIDUAL STRESS (after Ovseenko, et al [14])

1.3 Aim of the Present work

To study the microhardness and surface roughness, Conventional and Plasma Hot Machining tests are carried out on En-24 steel. Cutting forces and tool chip interface temperature are also measured. Non transferred arc mode of plasma heating is used because of convenience of operation.

CHAPTER-2

EXPERIMENTAL SET-UP AND PROCEDURE

2.1 General

In the present investigation, Plasma Hot Machining experiments have been carried out on En-24 steel to study cutting forces, tool chip interface temperature, surface finish and microhardness of the machined surface. A comparative study between Plasma Hot Machining and Conventional Machining is made.

2.2 Instrumentation

The schematic diagram of the experimental set up is shown in Fig. 8 .

The micro plasma welding unit with following specifications is used as a heat source in Hot Machining.

Input

Supply -200/250 V, Single Ø , 50 C/S

Voltage tappings- 200/225 V, 225/250V

Maximum KVA- 2.75

Maximum input current- 12 Amps

Output

Main arc

O.C. voltage- 100 V nominal, 150 V peak

Low range current- 0.1 to 2.0 Amps

High range current- 1.5 to 15 Amps

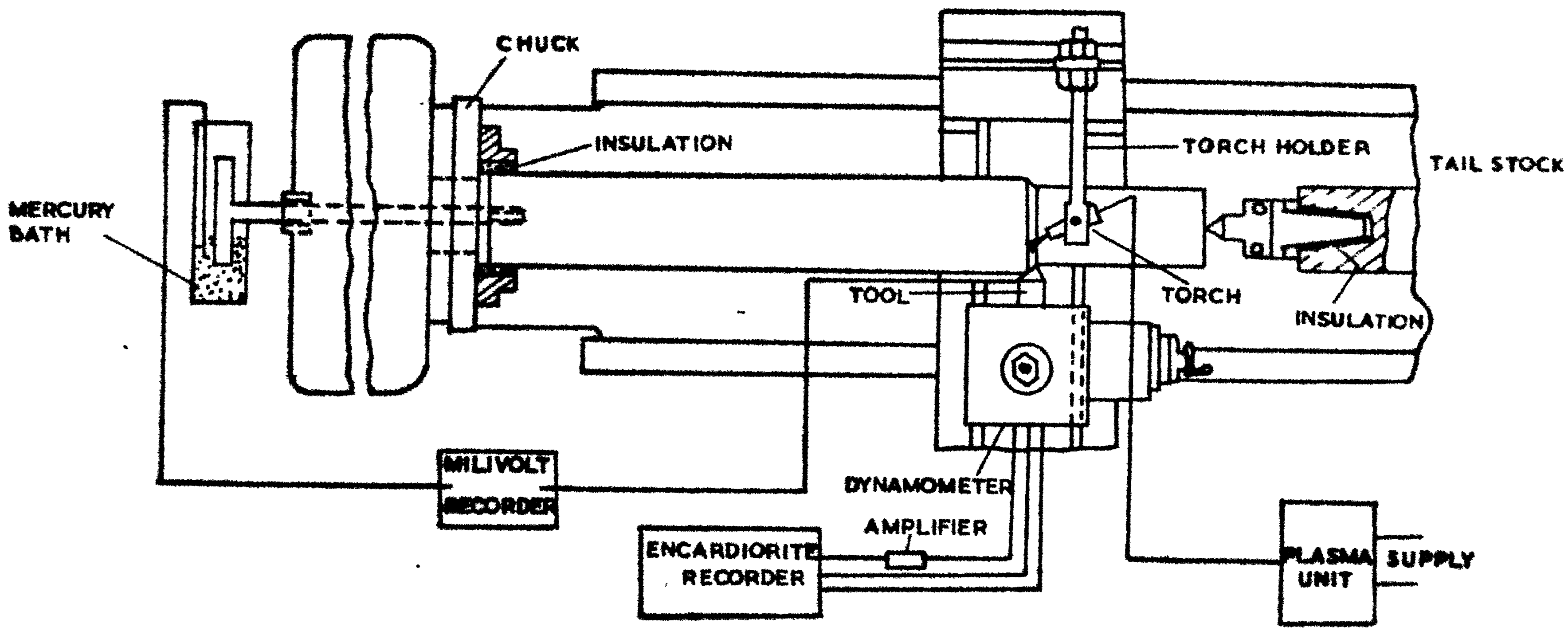


FIG.8 SCHEMATIC DIAGRAM OF THE EXPTL. SET-UP FOR PLASMA HOT MACHINING

Pilot arc

O.C. Voltage- 100 V nominal, 150 V peak

Striking current- 6 Amps, at 28 V

Running current- 2.5 Amps. at 24 V

Argon gas is used as the plasma generating gas.

2.2.1 Torch Holder

The torch holder designed and fabricated by Chattopadhyaya [15] is used. The torch holder has provision to vary torch position with respect to tool, stand-off distance of the torch from work piece and incident angle of the plasma jet on the work piece.

2.2.2 Three Dimensional Lathe Tool Dynamometer

A three dimensional lathe tool dynamometer (Fig. 9) is designed with the capacity of 150, 100 and 200 Kg in x,y and z directions respectively on the principles given in references [16, 17, 18] . The dynamometer is made of mild steel and consists of two extended octogonal rings one above the other . Preliminary tests showed that the tool vibrated violently due to the low rigidity of the dynamometer in dynamic loading conditions. To increase the rigidity of the dynamometer two circular rings are fixed as shown in Fig. 9.

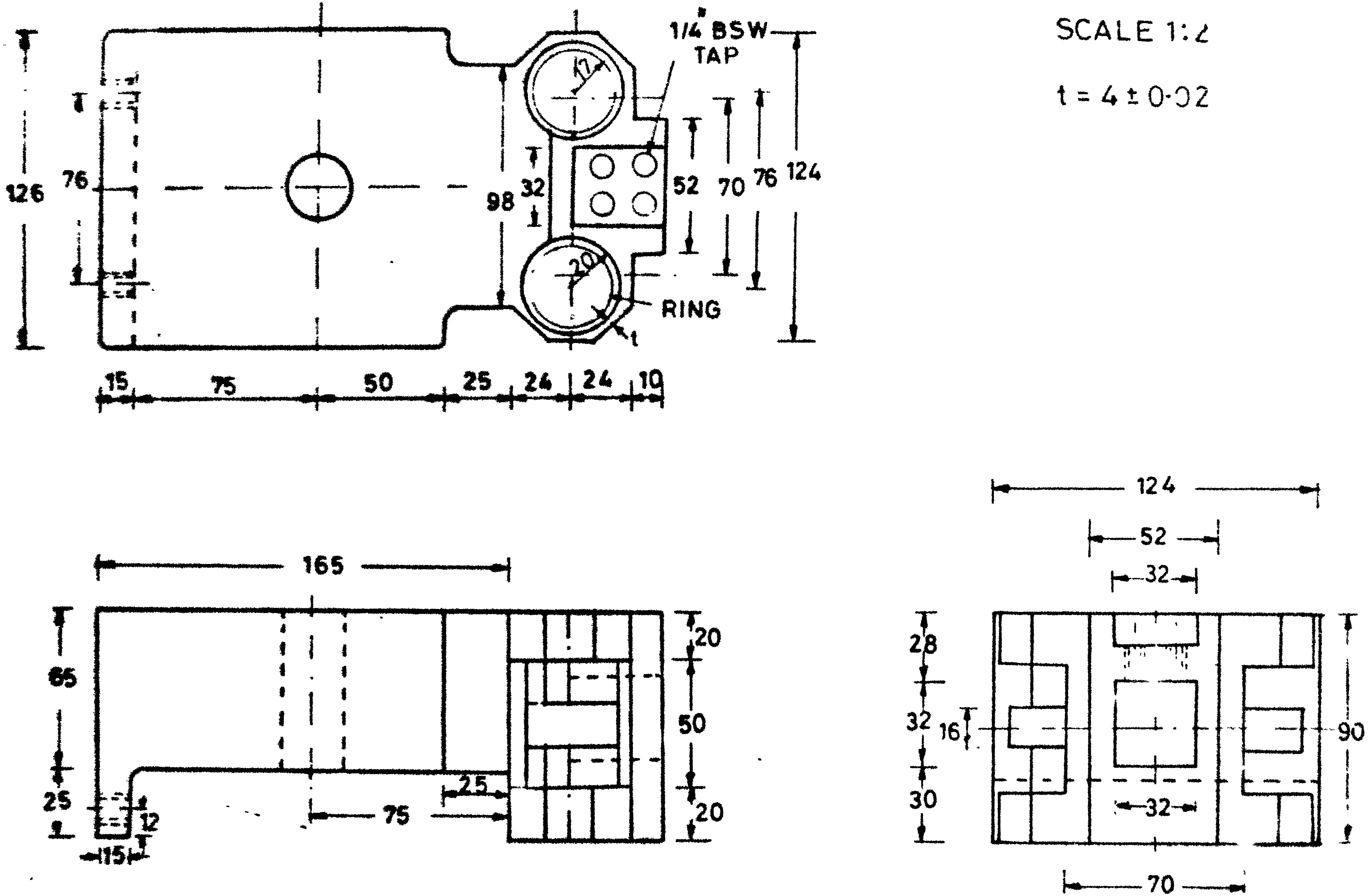


Fig. 9 Three dimension lathe tool dynamometer

Sixteen SR-4 paper based resistance type strain gages (500 ohm resistance and 2.1 gage factor) are cemented on the dynamometer as shown in Fig. 10. The gages are connected to form wheat stone bridge circuits such that cross sensitivity between the force components is minimised. The connections of the gages for measuring forces in the three directions are shown in Fig. 11.

The dynamometer is calibrated by fixing it on the Horizontal Milling Machine table (Fig. 12) . A 25 mm square mild steel bar is fixed in the position of tool. Loading is done by moving the work table. A proving ring of 500 pounds capacity is used to measure the loads applied . The voltage change in wheat stone bridge circuits are recorded by an encardiorite recorder . The calibration for each force components is made one after the other by changing the loading direction. Calibration curves for the three components are shown in Fig. 13 . Cross response is found to be less than 1%.

2.3 Specimen Preparation

En-24 steel bar is turned to the dimensions shown in Fig. 14 to make several specimen of 6 mm length and 42 mm diameter . Specimen are prepared by Conventional Machining with sufficient coolant supply.

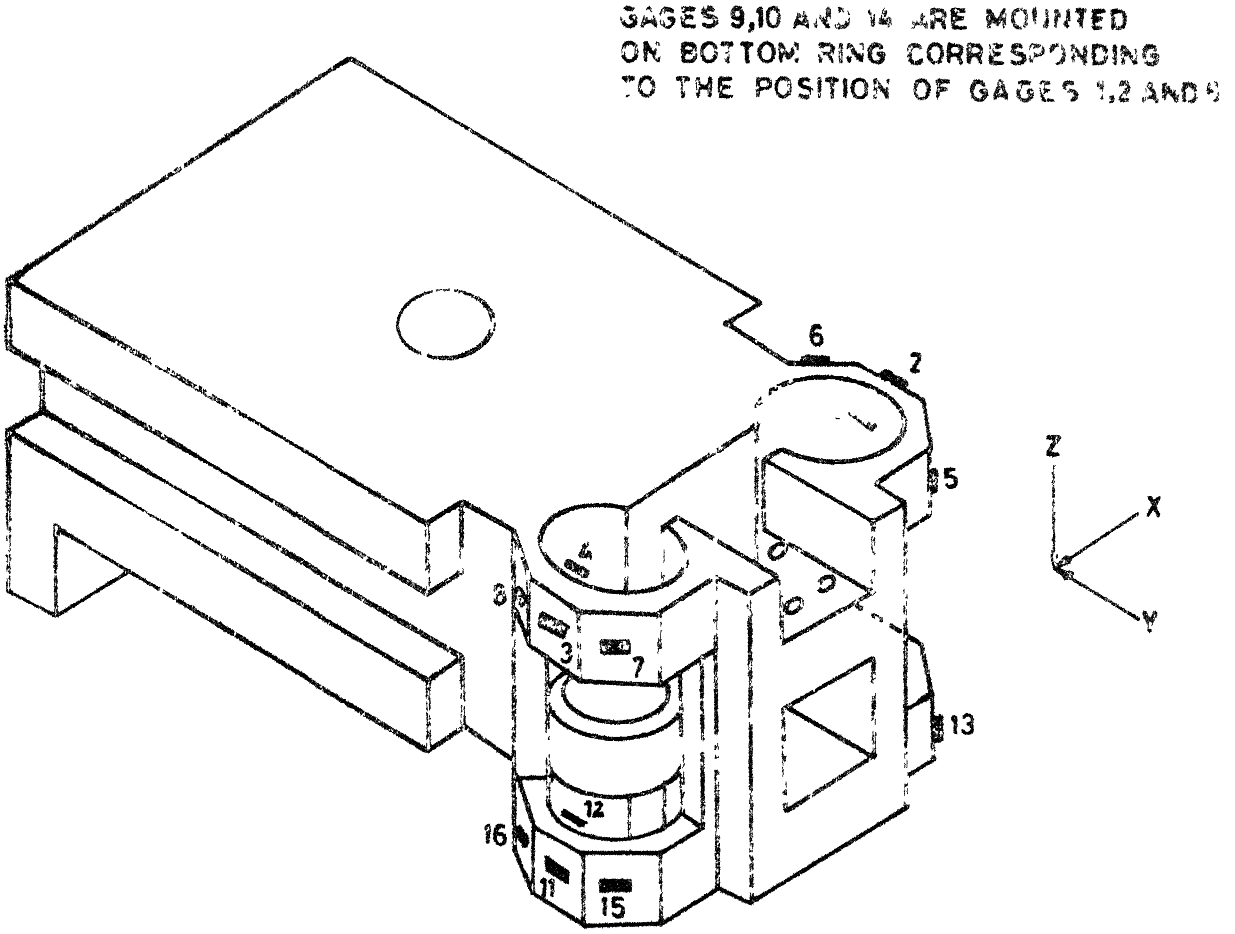


FIG.10 THREE COMPONENT LATHE TOOL DYNAMOMETER
WITH GAGES MOUNTED

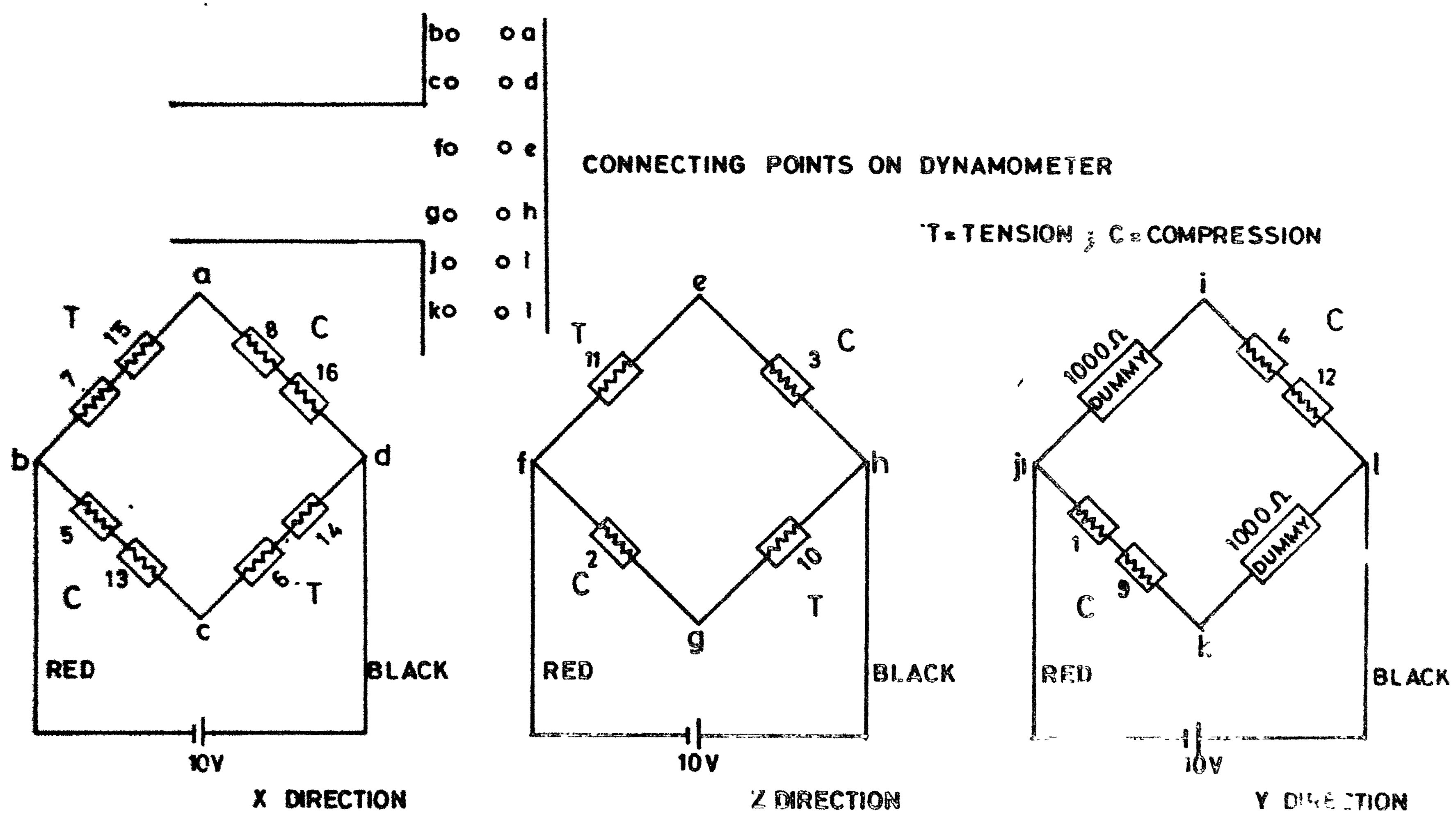


FIG. 11 WHEASTONE BRIDGE CIRCUITS FOR MEASURING FORCES IN THREE DIRECTIONS

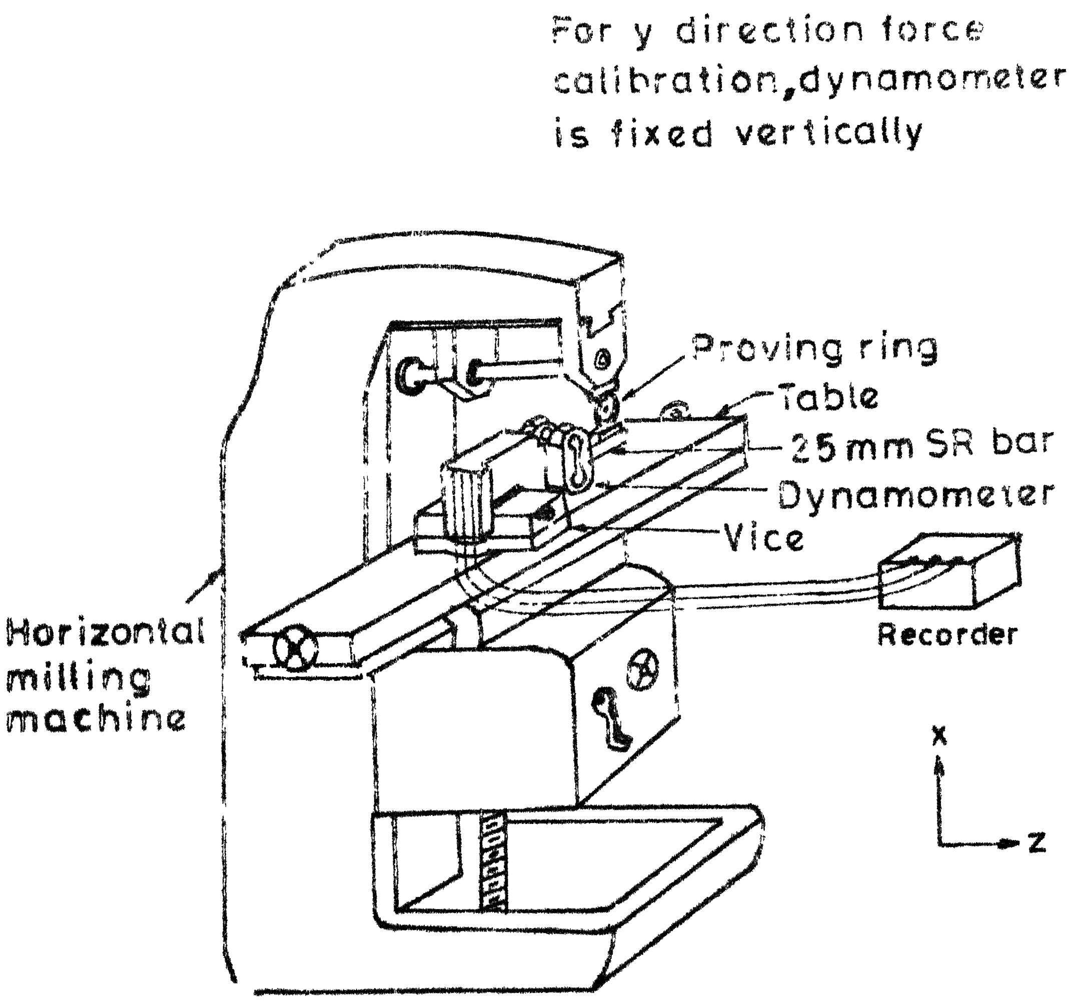


Fig.12 Set-up for dynamometer calibration

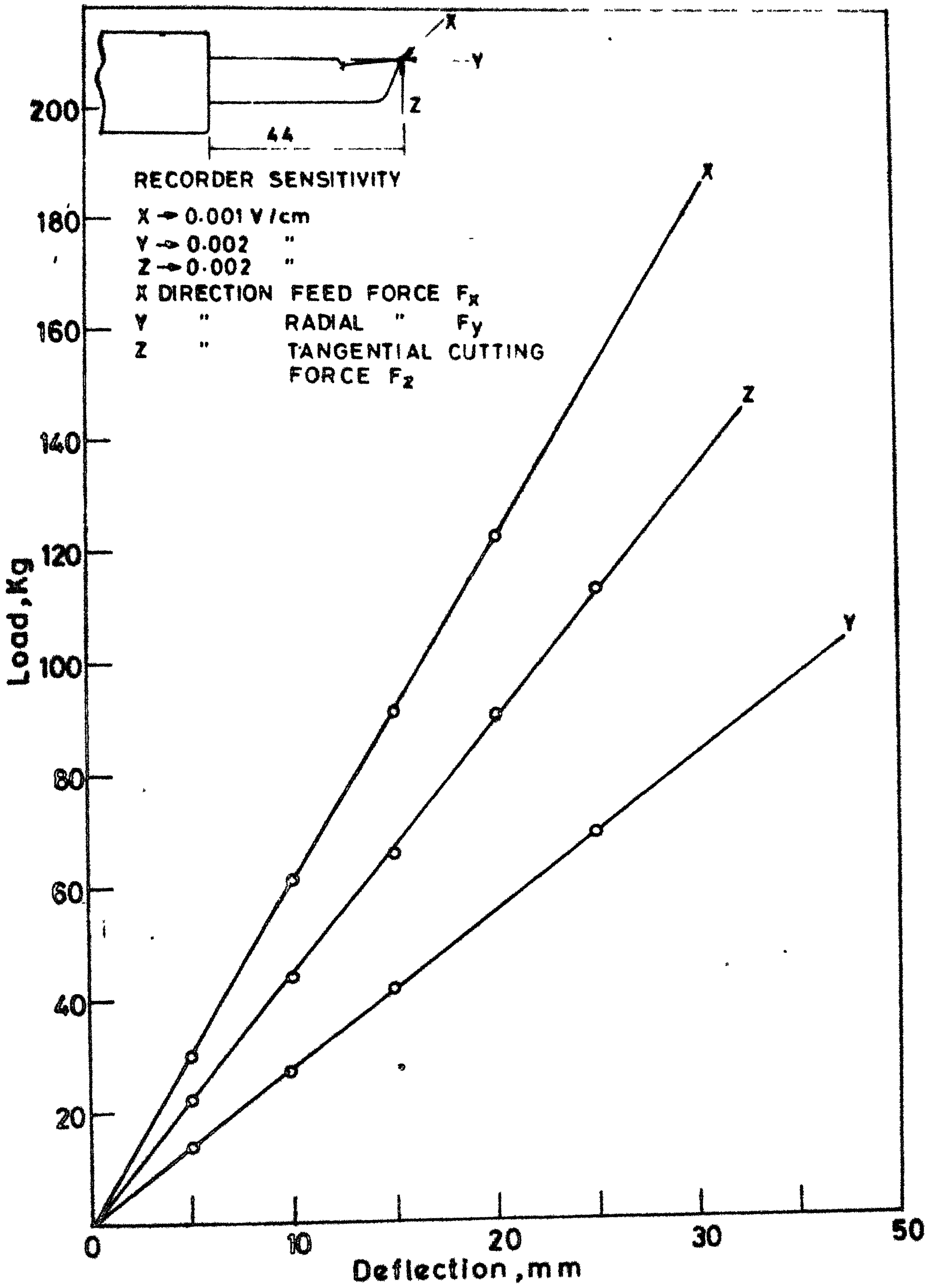


FIG.13 CALIBRATION CURVES FOR THREE DIMENSIONAL LATHE TOOL DYNAMOMETER

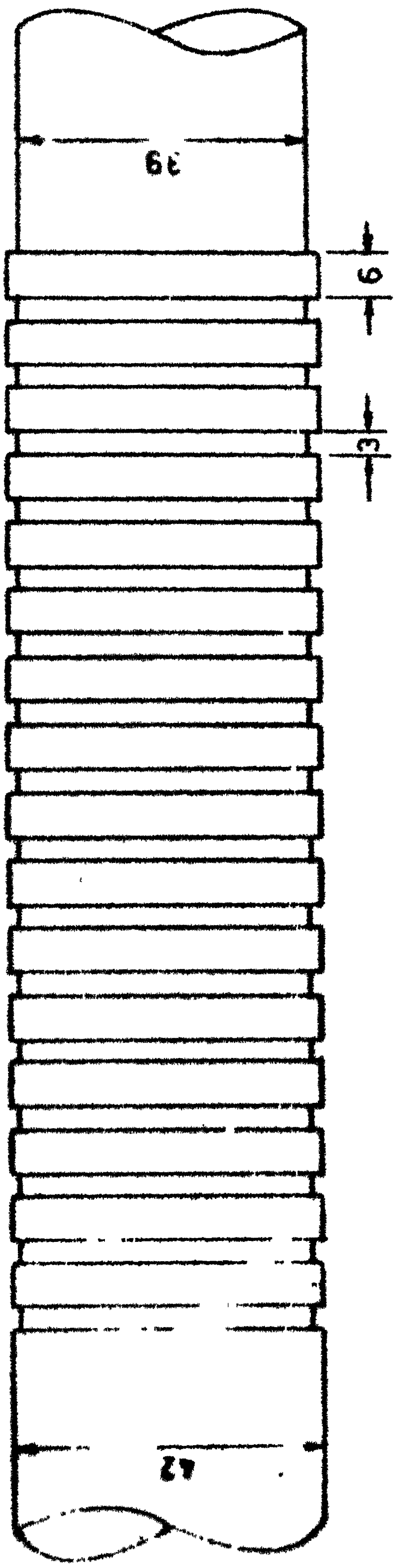


FIG.14 SPECIMEN FOR CUTTING TESTS

2.4 Experimental Procedure

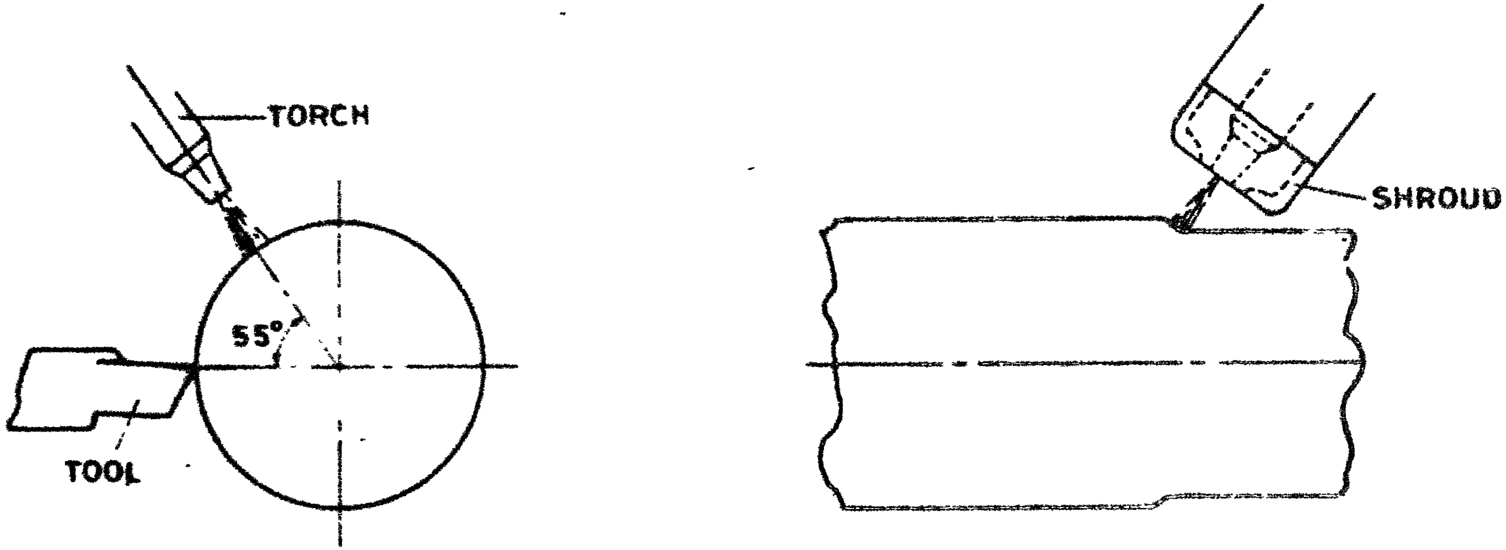
The Conventional Machining tests are carried out on En-24 steel for a range of cutting speeds from 52 to 166 m/min at a constant feed and depth of cut of 0.15 mm/rev and 1 mm respectively. Sandvic Coromant indexable tool holder (R and L 174.2 - 2525 M) with throw away tips having geometry 0, 6, 11, 5, 15, 15, 1.2 is used as cutting tool. Fresh edge is used for each test.

The Plasma Hot Machining tests are performed by keeping the torch at a stand-off distance of 11 mm and at a distance of 20 mm from cutting edge along the circumference of the work piece as shown in Fig. 15a. The cutting conditions used are same as that of the conventional cutting tests. The optimal parameters of the torch [19] (15 amps current, Argon gas pressure of 6 Kg/cm^2 and gas flow rate of 3 litres/ min) are used.

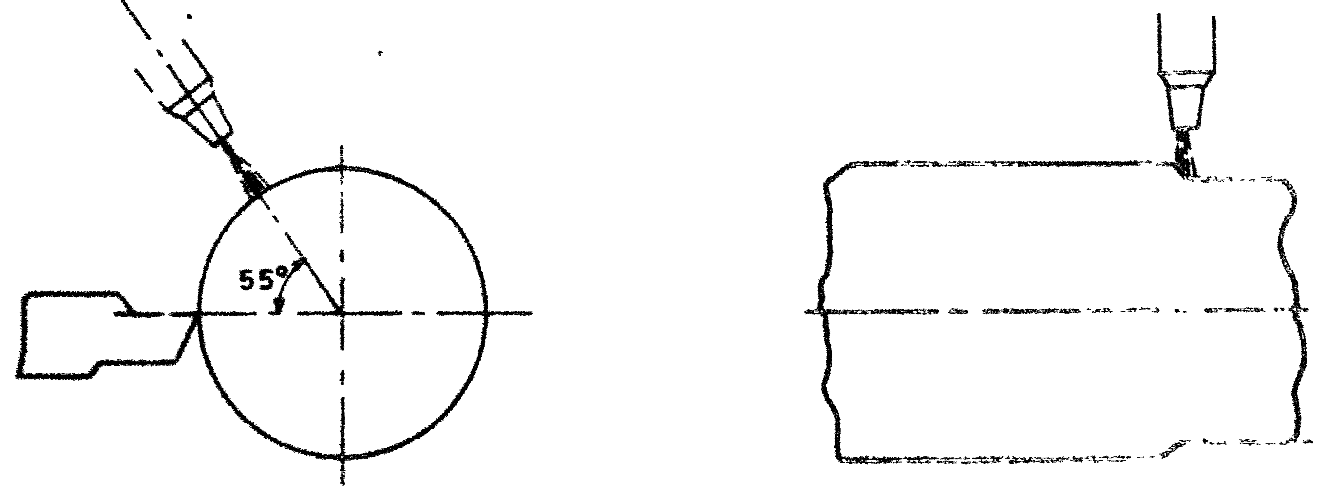
To study the effect of stand-off distance experiments are conducted with stand-off distances of 4, 6, 8 and 10 mm at cutting speeds of 52 m/min and 105 m/min. A modified torch work configuration shown in Fig. 15b is used to avoid obstruction of porcelain shroud.

2.4.1 Measurement of Temperature

Tool work thermocouple[15] is used to measure chip



(a) FOR 11mm STAND-OFF



(b) FOR 4,6,8 AND 10mm STAND-OFF

FIG. 15 TORCH WORK CONFIGURATION

tool interface temperature (Fig. 8) . The tool work contact area serves as a hot junction in a thermo-electric circuit and the EMF generated is proportional to its temperature. Tool is insulated from dynamometer with 2 mm milar sheet and work piece is insulated from lathe machine by 3 mm thick fibre. A copper disc is fixed to one end of the the work piece. The copper disc rotates in a mercury bath to make a firm electrical connection. EMF generated by tool work thermocouple is recorded on a strip chart recorder. Temperature is read from the EMF and temperature calibration curve [15] for En-24 steel- tungsten carbide thermocouple Fig. 16.

2.4.2 Measurement of Cutting Forces

The cutting forces are measured by using three dimensional lathe tool dynamometer . The dynamometer with tool fixed in position is mounted on the compound slide of the lathe as shown in Fig. 8. The cutting experiments are carried out and the cutting forces are recorded by encordiorite recorder. Recorder sensitivity of 0.001 V/Cm is used.

2.4.3 Measurement of Surface Roughness

The RMS value of surface roughness of machined surface is measured using a portable profilometer (Bendix Corporation, U.S.A.) which employs a stylus that is

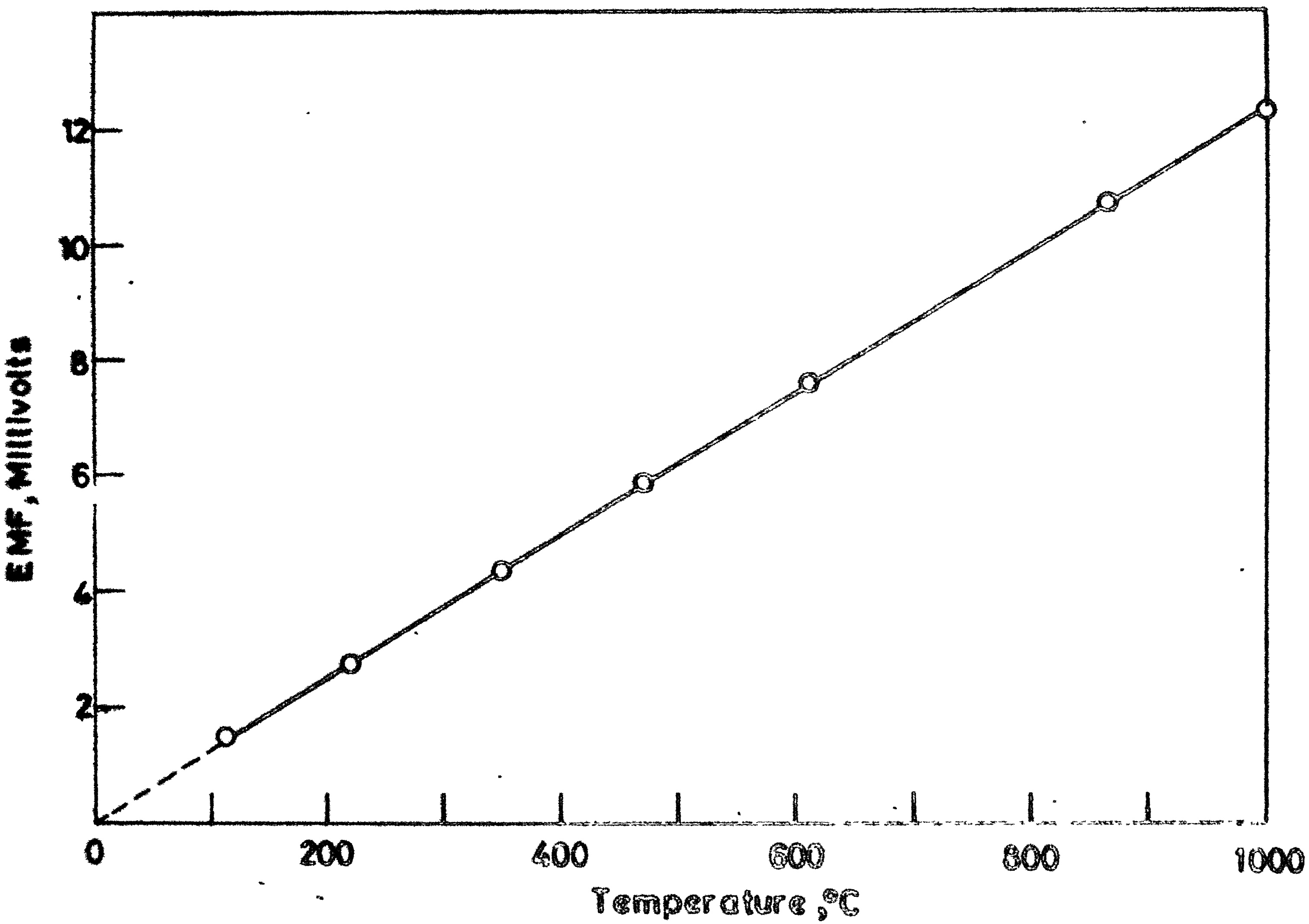


FIG.16 TEMPERATURE CALIBRATION CURVE FOR EN-24 STEEL-WC THERMOCOUPLE [15]

dragged across the machined surface. A stroke length of 3 mm is used for the stylus.

2.4.4 Measurement of Microhardness

The machined specimen are cut as shown in Fig. 17a. The machined surface of the specimen is polished . The NU-2 microscope with microhardness testing attachment is used to measure the microhardness. A special vice is designed for the purpose of mounting the specimen on the microscope table (Fig. 17b). A diamond indentor (Pyramid with an angle of 136^{o} between opposite faces) and 80 grams load is used for making indentation. The largest diagonal of the indentation is measured using magnification of 15x25. The eye piece scale is calibrated according to the magnification used.

Microhardness is calculated using the formula,

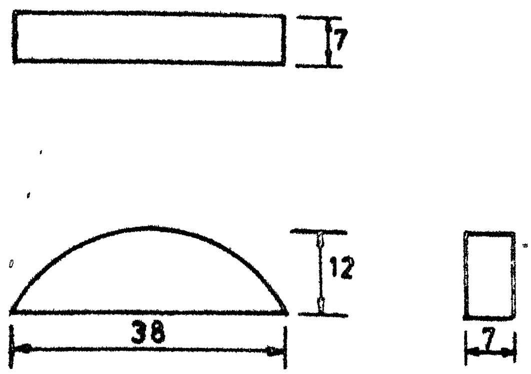
$$H = \frac{1.854 \times P}{(d)^2}$$

where

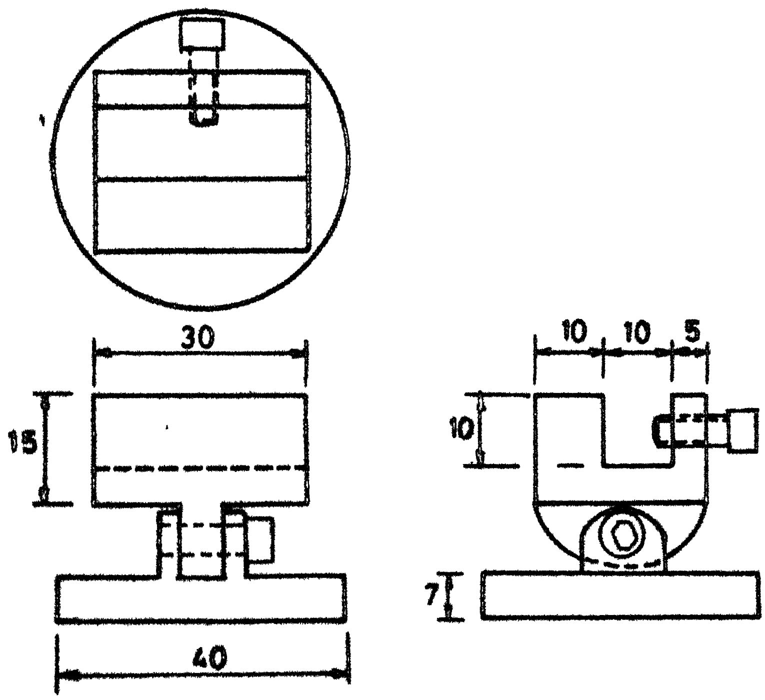
H is hardness in Kg/mm^2,

P is Load in Kgf and,

d is diagonal of square indentation in mm.



(a) SPECIMEN FOR MICROHARDNESS TEST



(b) VICE FOR MICROHARDNESS TEST

FIG. 17

CHAPTER-3

RESULTS AND DISCUSSION

3.1. General

The results of experiments conducted on Conventional Machining and Plasma Hot Machining are presented in this chapter. The effects of cutting speed and stand-off distance on cutting forces, tool chip interface temperature, surface finish and microhardness are discussed. A comparison between Conventional Machining and Plasma Hot Machining is made.

3.2 Cutting Forces

Figure 18 represents the behaviour of cutting forces with speed ranging from 52 m/min to 166 m/min for Conventional Machining and Plasma Hot Machining with 11 mm stand- off distance. It is observed that cutting forces reduce by about 10% during machining with plasma heating. The reduction in forces is some what higher at lower speeds.

Figure 19 represents the variation of cutting forces with torch stand-off distance for cutting speeds of 52 m/min and 105 m/min . The cutting forces increase marginally (by about 4%) as the stand-off distance is increased from 4 to 10 mm. Cutting forces are minimum at 4 mm stand-off distance. Reducing stand-off distance further is not possible due to interference of nozzle and flame.

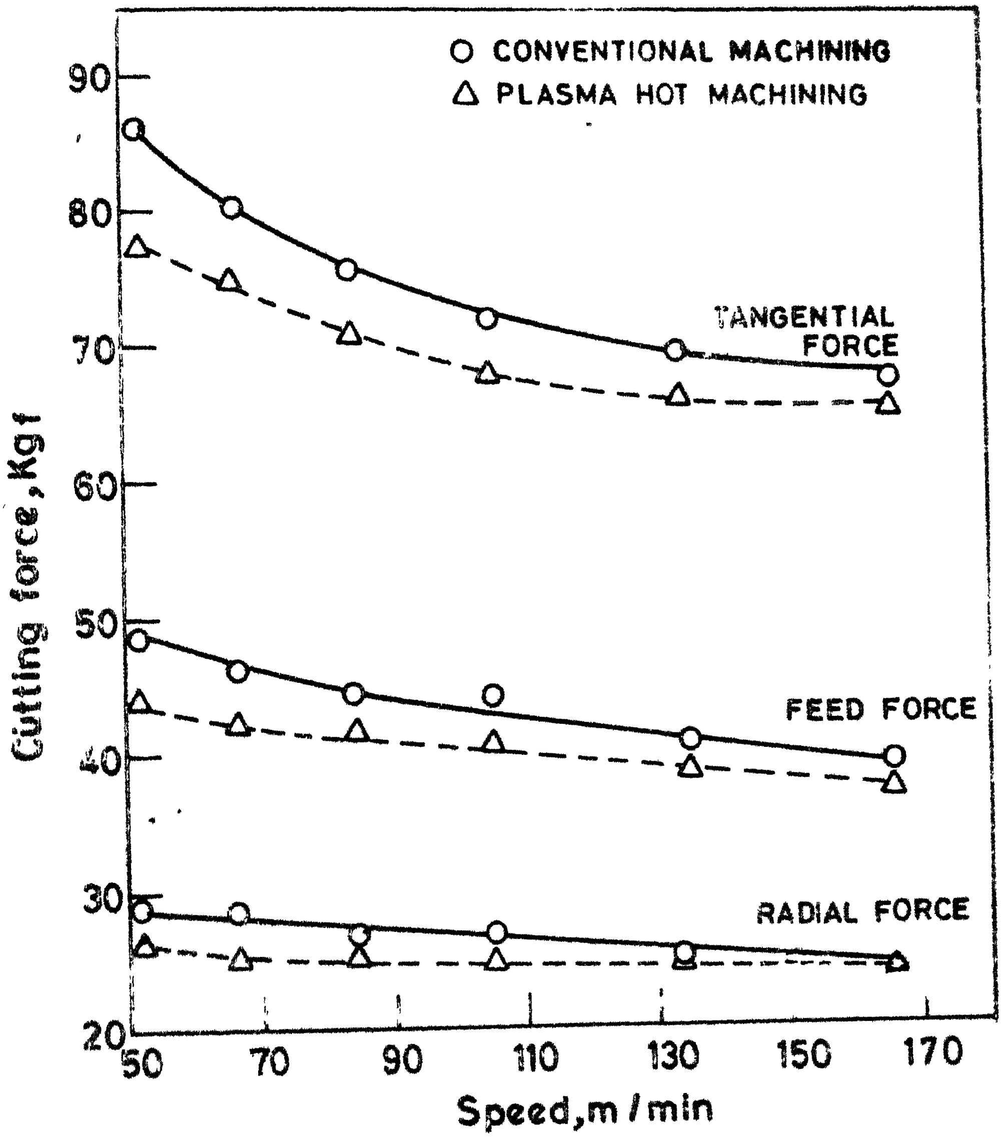


FIG. 18 VARIATION OF CUTTING FORCES WITH SPEED FOR 11mm STAND-OFF

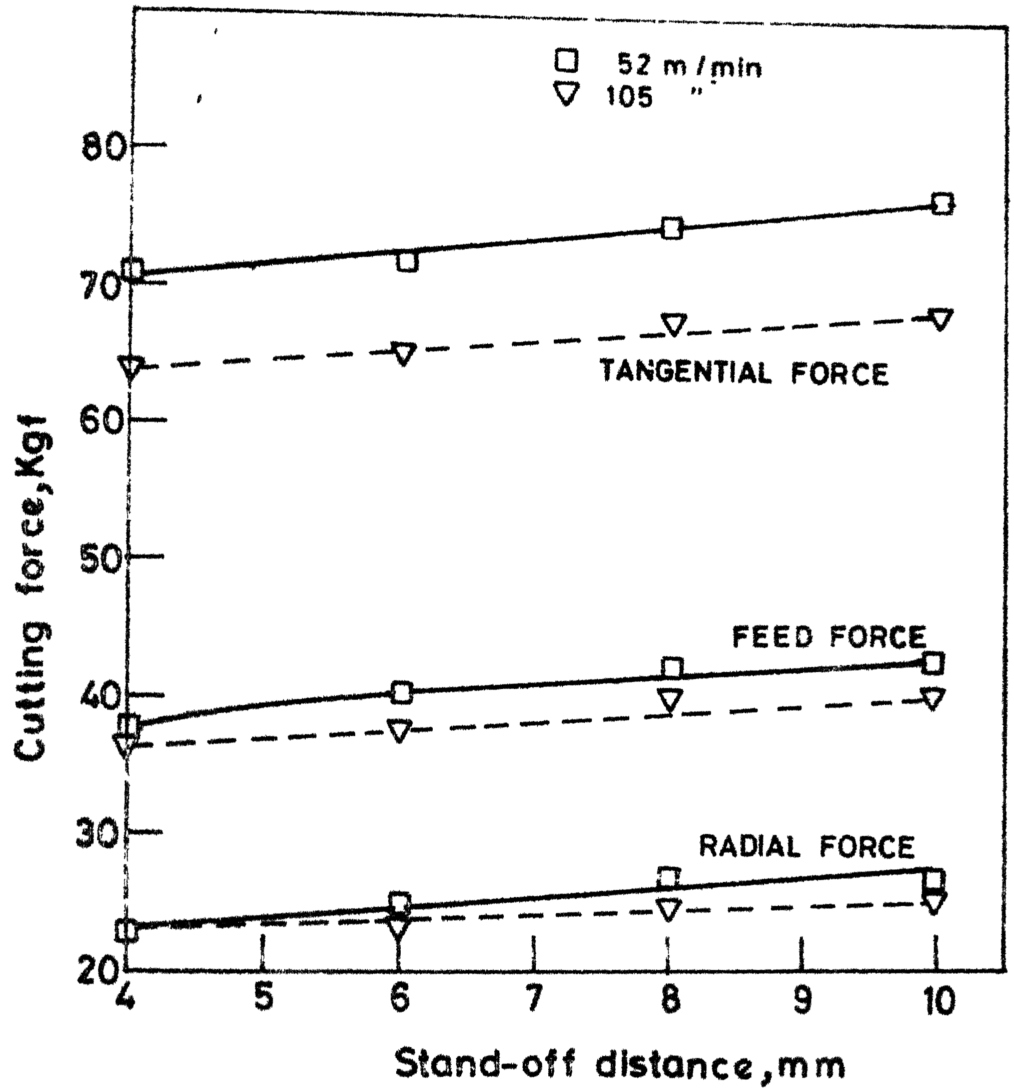


FIG.19 VARIATION OF CUTTING FORCES WITH STAND-OFF DISTANCE

Above results show that plasma heating reduces tangential cutting force by aproximately 15% and feed force by 24% at 52 m/min cutting speed and 4 mm stand-off distance for the available power of torch.

The reduction in cutting forces during Plasma Hot Machining is due to the reduced strength of work material at higher temperature. (Fig. 1)

3.3 Tool Chip Interface Temperature

Figure 20 represents the variation of interface temperature with speed for Conventional and Plasma Hot Machining for a stand-off distance of 11 mm. In both the cases tool chip interface temperature increases with increase in speed. The increase in temperature during Hot Machining is nearly 40% at 52 m/min and is 10% at 166 m/min . The increase is more at lower speeds than at higher speeds due to the fact that heat energy transfer efficiency is more at lower speeds. Hinds and Almeida [7] found that efficiency of heat energy transfer of plasma flame to the work piece reduces with increase in both cutting speeds as well as stand-off distance (Fig. 2) . The decrease in heat transfer efficiency is due to lower heat energy input to the cutting zone per unit volume of material at higher speeds.

Figure 21 presents the variation of interface temperature with stand-off distance for cutting speeds of 52 m/min and 105 m/min . The temperature decreases with

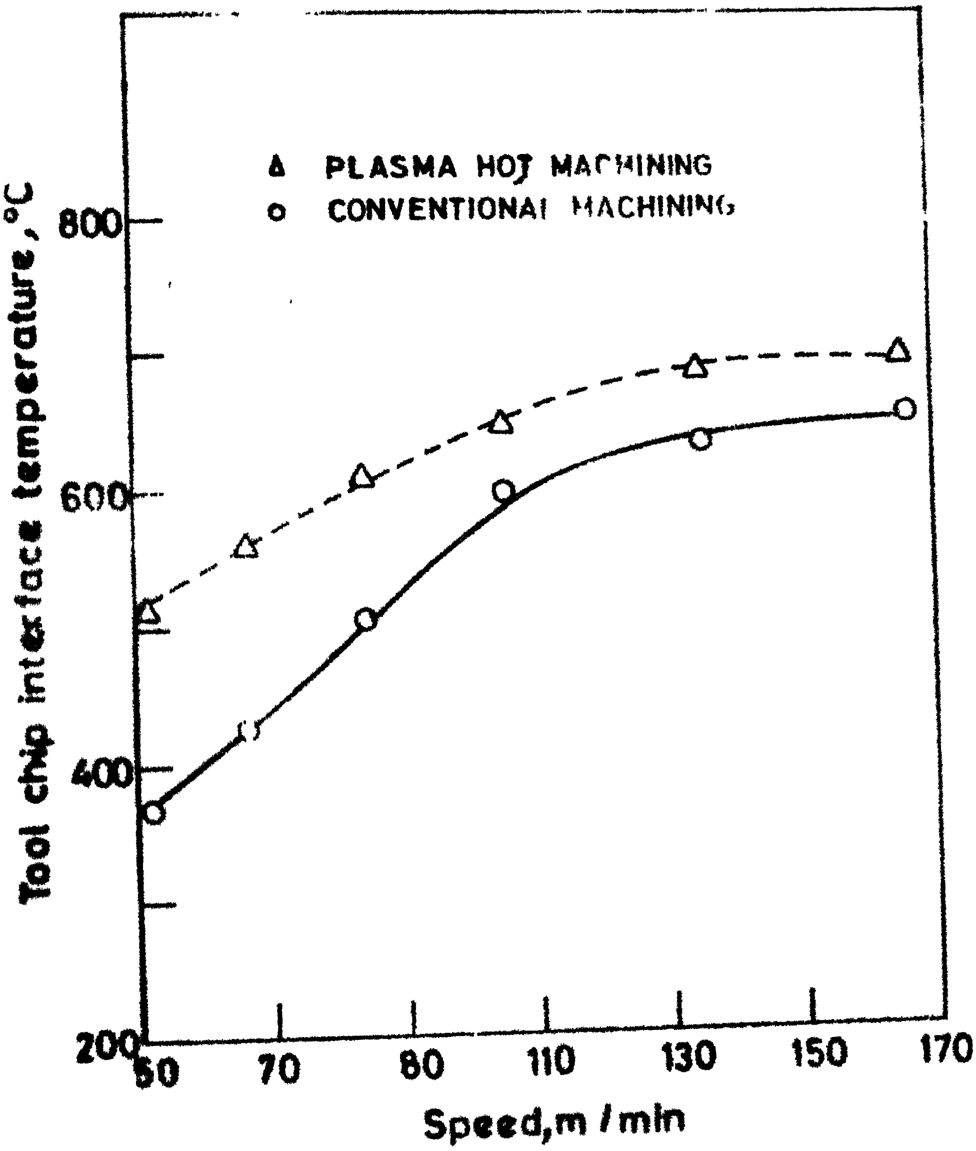


FIG.20 VARIATION OF TOOL CHIP INTERFACE TEMPERATURE WITH CUTTING SPEED FOR 11 mm STAND-OFF DISTANCE

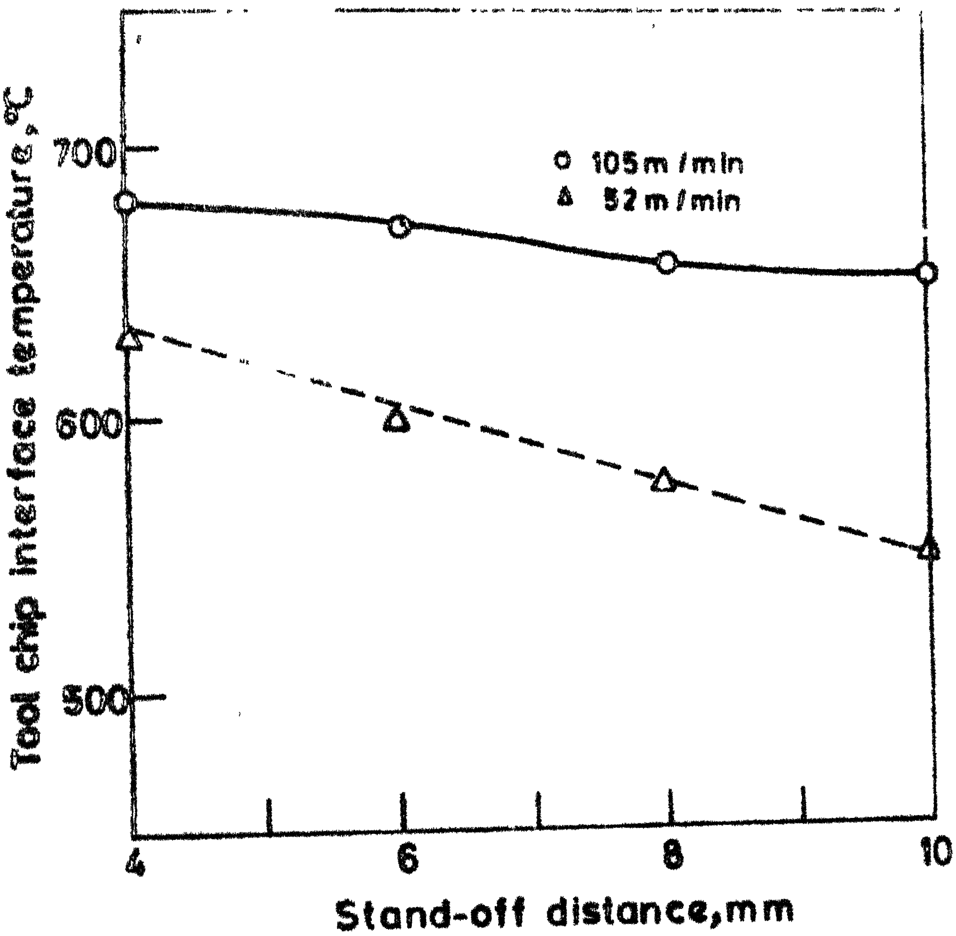


FIG.21 VARIATION OF TOOL CHIP INTERFACE TEMPERATURE WITH STAND-OFF DISTANCE

increase in stand-off distance, the rate of decrease being higher at lower speed.

3.4 Theoretical Estimate of Average Pre-heat Temperature

The estimate of pre-heat temperature at which the work piece material approaches the cutting edge [9] due to plasma arc heating alone is made using equation,

$$T = \frac{\beta W \eta}{2 \lambda L b \sqrt{\pi k_1}} \exp [-k_1 a^2] \ \mathrm{erf} [\frac{b}{2} \sqrt{\frac{k_0 k_1}{k_0 + k_1}}]$$

T is the temperature set up in a solid by a rapidly moving normal circular heat source (^{o}C)

W is the power of plasmotron (watts)

η is the thermal efficiency of the plasmotron

λ is the thermal conductivity of work piece material ($w/Cm^{o}C$)

a and b are the thickness and width of cut respectively

L is the distance of the plasma flame from the cutting edge, lead (cm)

k_o= 1/ Area of plasma flame spot ($1/cm^2$)

k_1= V/ (4ω L) ($1/cm^2$)

where V is the cutting speed (cm/s)

ω is the thermal diffusivity of the work piece material (cm^2/s)

β is the coefficient which allows for accumulation of

heat in the work piece during machining. It depends on the cutting rates and properties of the work piece material. For steels it ranges from 1.2 to 1.5 .

In the present investigation work piece is En-24 steel and heating source is a micro plasma welding torch.

A computer program is made to calculate the temperature of work piece for different cutting speed, depth of cut, width of cut, lead distance and spot diameter.

The values of the variables taken for calculation of temperature are listed below

W = 2250 watts

η = 60% [20]

En-24 Steel properties [21]

Thermal conductivity = 0.380926 w/(cm °C)

Density = 7.86 gm/cc

Specific heat C = 0.493948 Joules/(gm °C)

Figure 22 shows the dependence of temperature attained by the work piece on lead. Lead distance corresponding to maximum temperature increases with increase in speed. This is due to the time dependence of heat transfer .

Figure 23 shows the linear decrease in temperature with increase in spot diameter. This is due to the decrease in concentration of plasma flame with increase in spot area.

Figure 24 shows the variation of average temperature with the depth of the work piece for different cutting speeds The average temperature decreases as the depth increases.

The tool chip interface temperatures measured during Plasma Hot Machining shows similar trend as the theoretically estimated pre-heat temperatures.

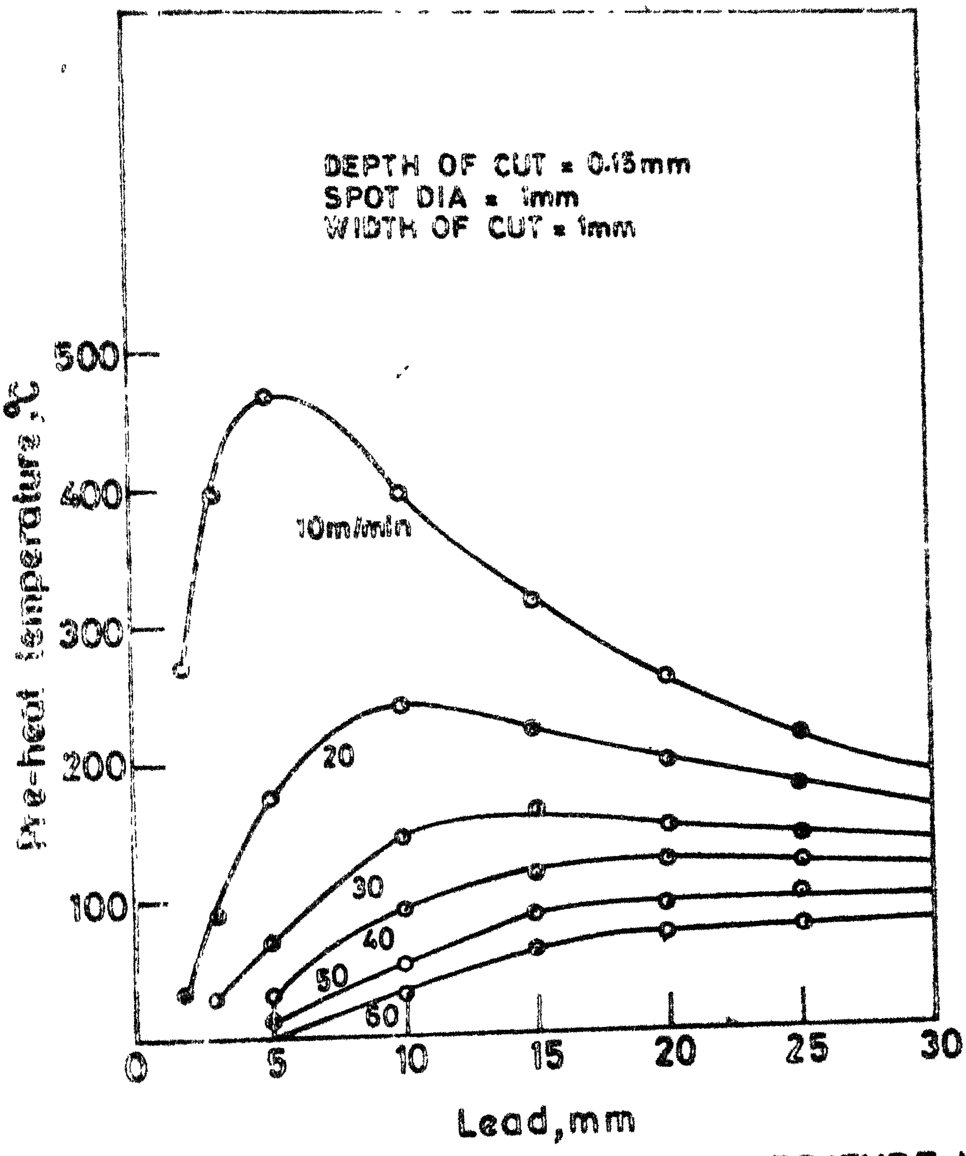


FIG.22 VARIATION OF PRE-HEAT TEMPERATURE WITH LEAD

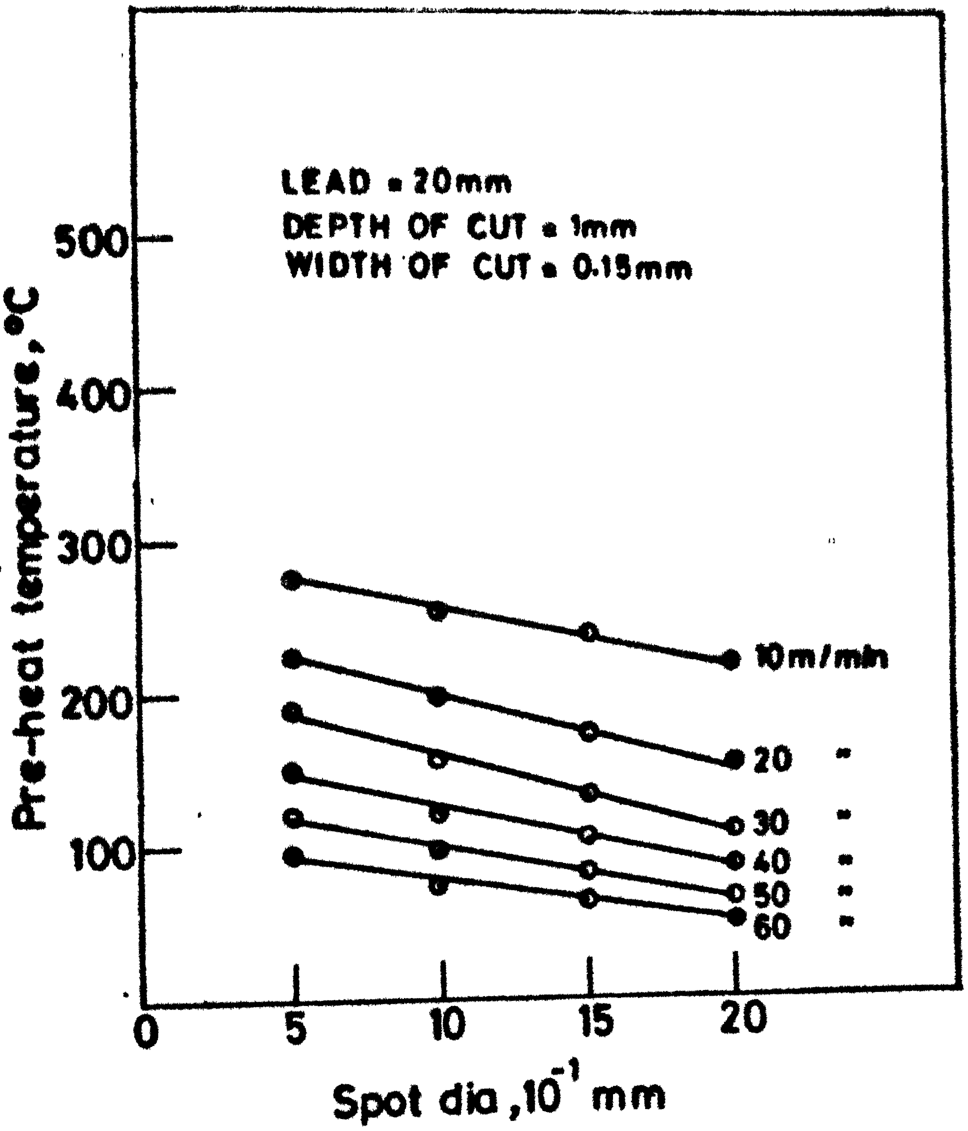


FIG.23 VARIATION OF PRE HEAT TEMPERATURE WITH SPUT DIAMETER OF THE PLASMA FLAME WHILE STRIKING THE WORKPIECE

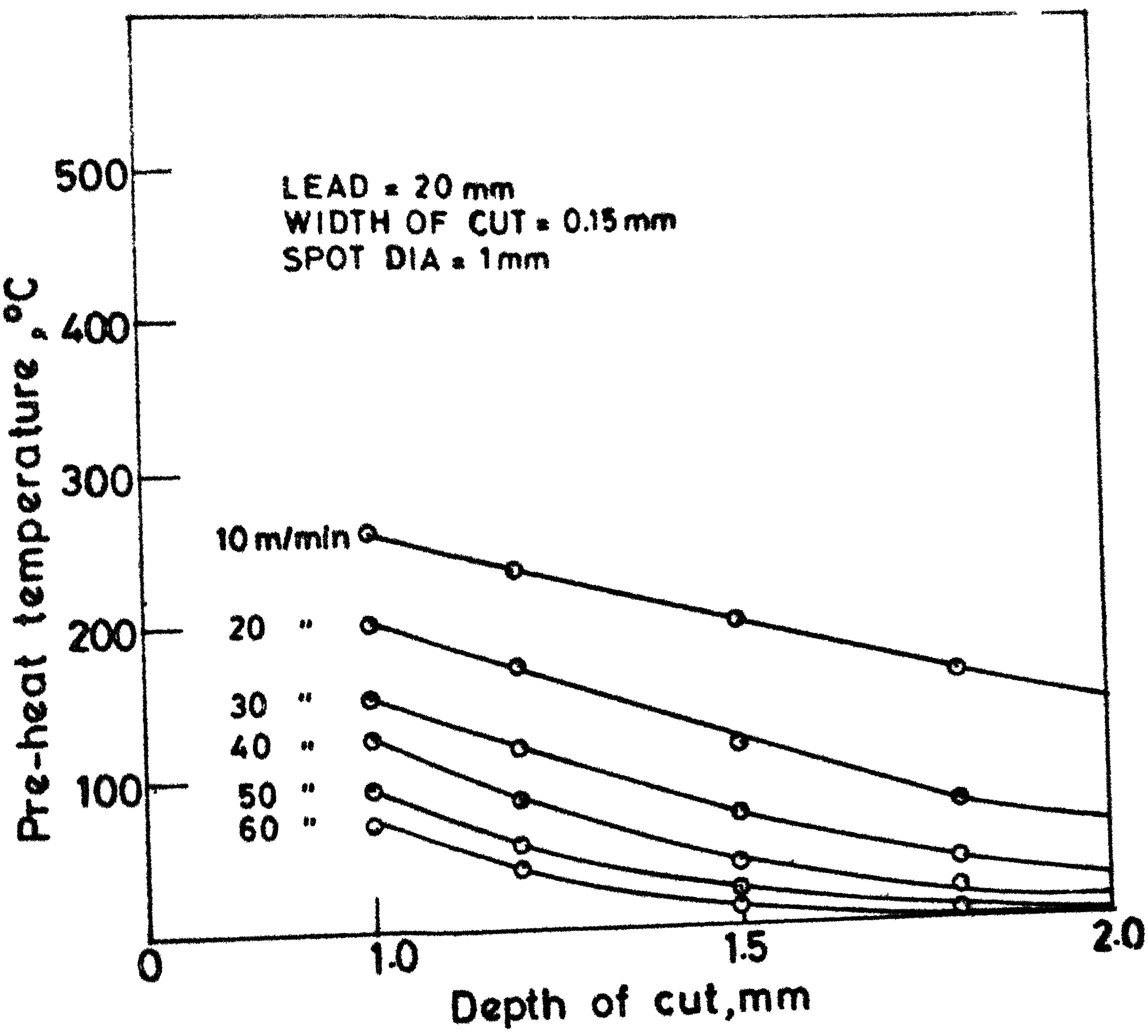


FIG.24 VARIATION OF PRE-HEAT TEMPERATURE WITH DEPTH OF CUT

3.5 Surface Roughness

Figure 25 shows the variation of surface roughness with cutting speed for Conventional Machining and Plasma Hot Machining. Surface roughness is lower by approximately 40% in the case of Plasma Hot Machining.

Figure 26 shows the variation of surface roughness with stand-off distance. Surface roughness reduces further with reduction of stand-off distance .

The reduction of surface roughness in Plasma Hot Machining can be attributed to lower tool wear [19] and tendency towards continuous chip formation.

3.6 Microhardness

Figure 27 shows the variation of microhardness with cutting speed for Conventional Machining and Plasma Hot Machining with 11 mm stand-off distance . Increase in microhardness is seen in the case of Plasma Hot Machining compared to Conventional Machining . At 52 m/min , the increase in hardness is approximately 8% .

In both the cases the microhardness increases parabolically with speed and at higher speeds the effect of heat is negligible .

Figure 28 indicates the effect of stand-off distance on the microhardness at cutting speeds of 52 m/min and 105 m/min. A further increase in microhardness is observed

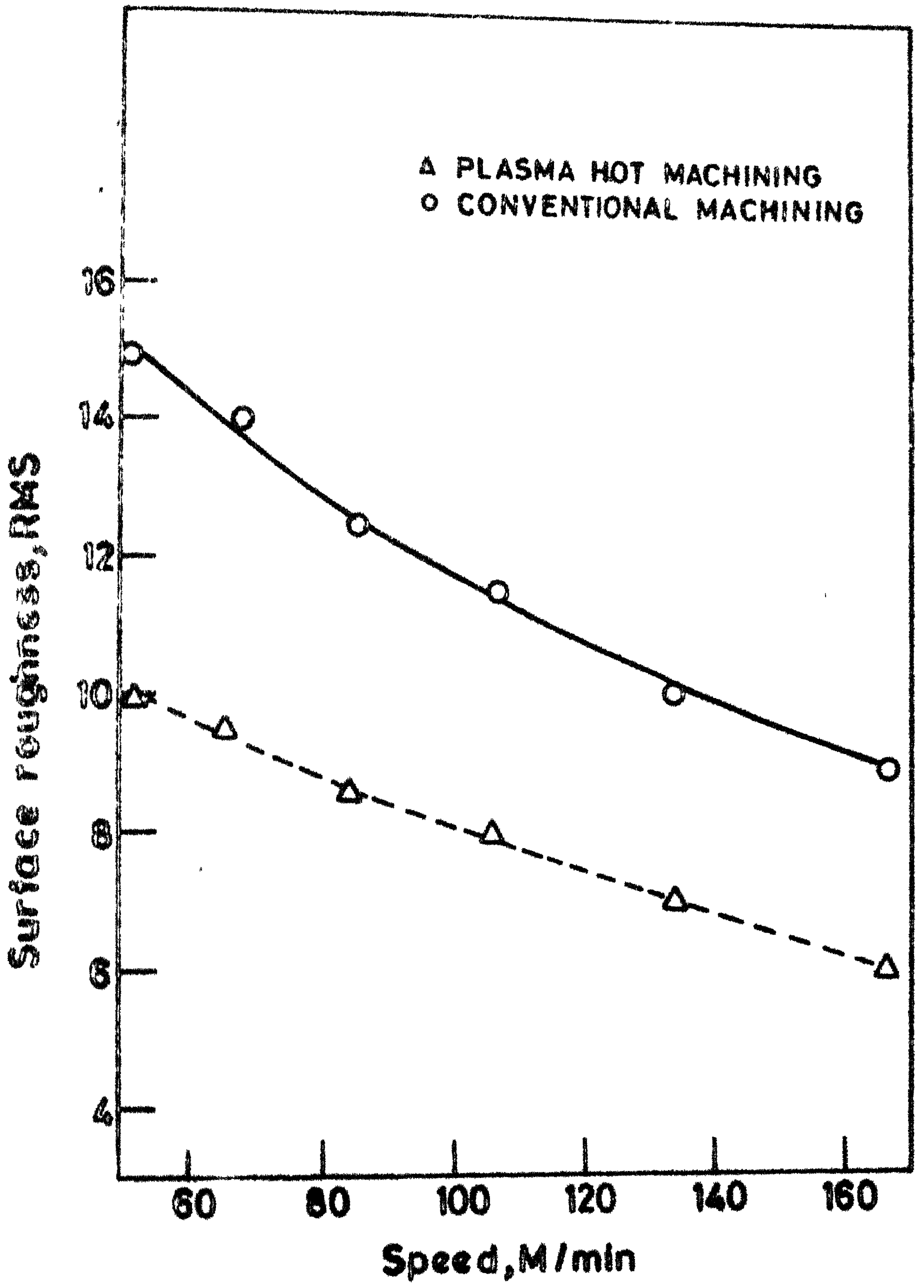


FIG. 25 VARIATION OF SURFACE ROUGHNESS WITH CUTTING SPEED FOR 11mm STAND OFF DISTANCE

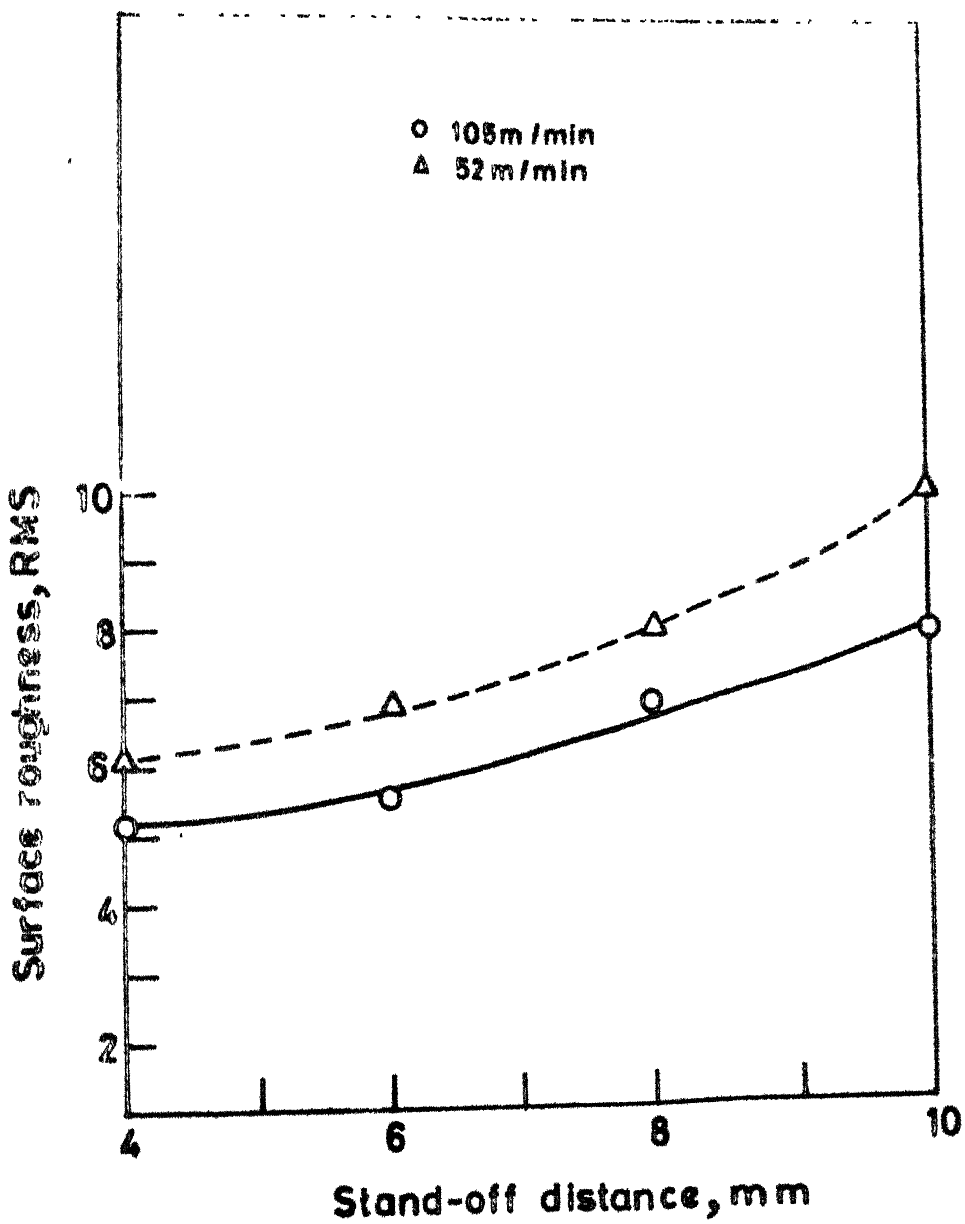


FIG.28 VARIATION OF SURFACE ROUGHNESS WITH STAND-OFF DISTANCE

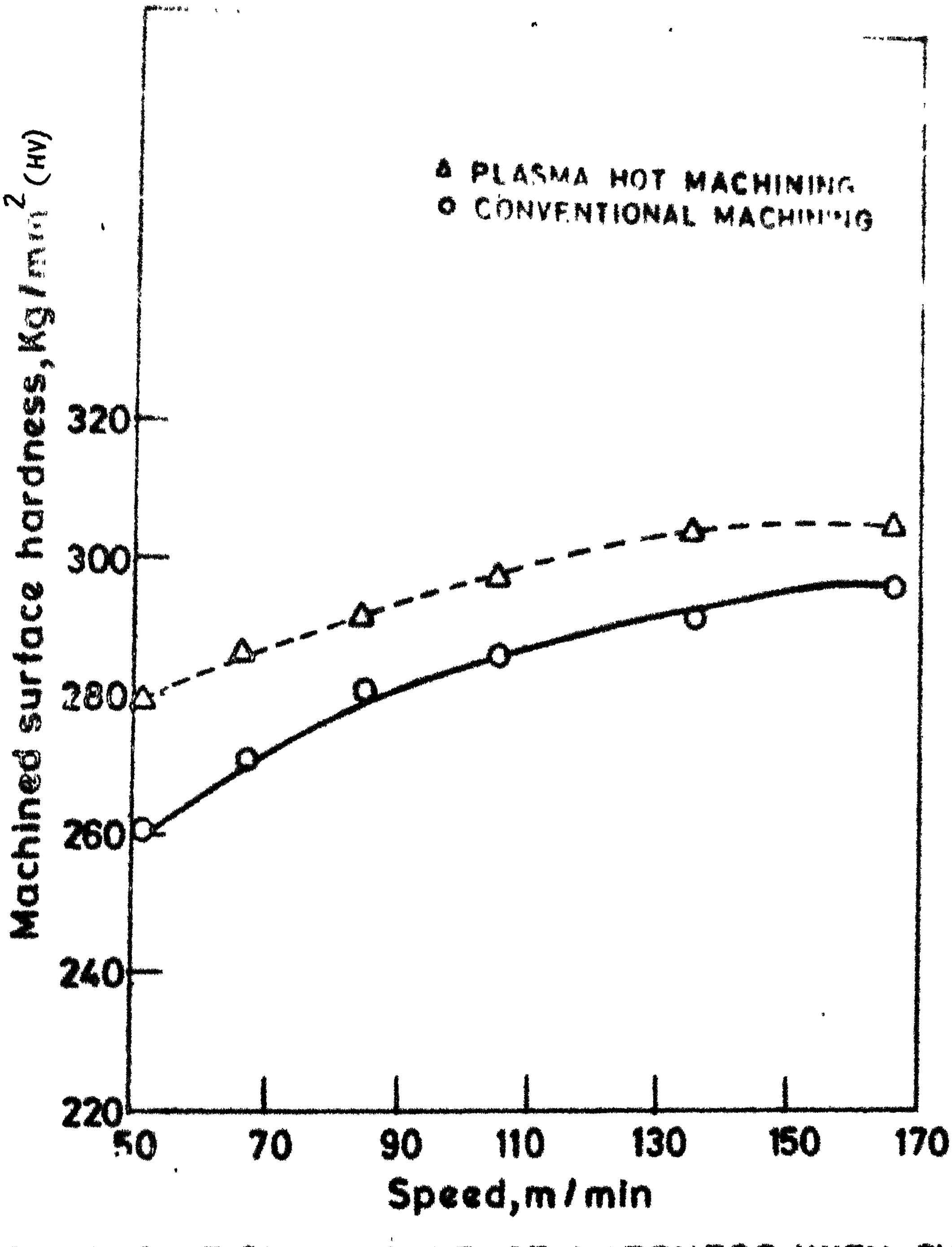


FIG. 27 VARIATION OF SURFACE HARDNESS WITH CUTTING SPEED FOR 11 mm STAND-OFF DISTANCE

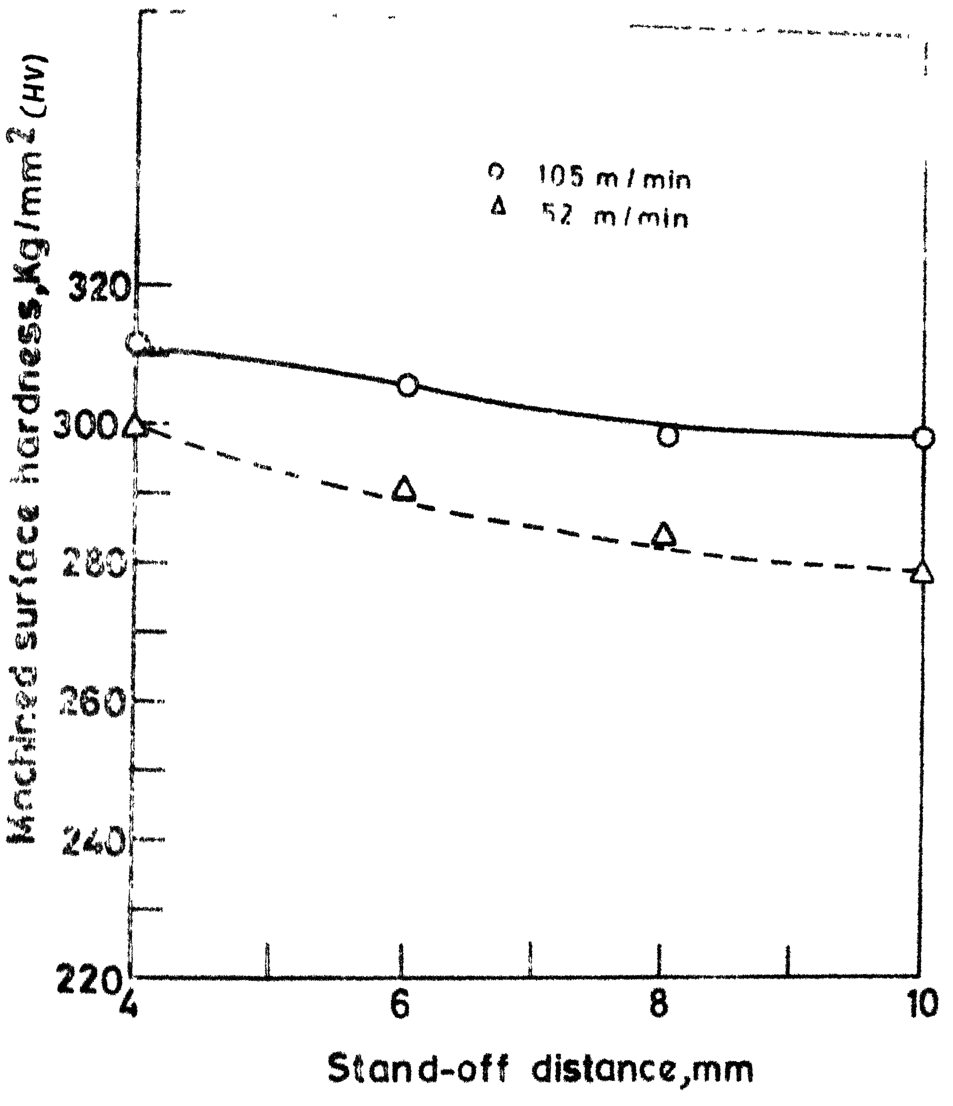


FIG.28 VARIATION OF SURFACE HARDNESS WITH STAND-OFF DISTANCE

at speed of 52 m/min and 4 mm stand-off distance compared to 11 mm stand-off distance.

Ovseenko et al[14] found that while machining high alloy cast iron pre-heating temperature upto 300 ^{o}c reduces the machined surface temperature specially at 60 m/min (Fig. 7a) and increases the formation of residual compressive stress in the surface layer (Fig. 7b).

The strength of the material is reduced due to pre-heating. This results in reduction of cutting forces and total temperature of the machined surface layer. Consequently the residual tensile stresses of dynamic origin are lowered compared with machining of unheated material. The resulting residual(compressive)stresses after machining with pre-heating are greater than when machining without it. This results in strengthening of surface layer leading to higher microhardness.

CHAPTER 4

CONCLUSIONS AND SCOPE FOR FUTURE WORK

The following conclusions are drawn from the results of cutting tests carried out on En-24 steel using carbide tipped tools by Conventional and Plasma Hot Machining at a feed of 0.15 mm/rev, depth of cut of 1 mm and speed ranging from 52 m/min to 166 m/min .

(1) The cutting forces reduce in the case of Plasma Hot Machining compared to Conventional Machining. The reduction is more at lower speeds than at higher speeds. The tangential cutting force is reduced by 15% and feed force is reduced by 24% . The decrease in stand-off distance helps in reducing cutting forces.

(2) The tool chip interface temperature increases during Plasma Hot Machining . The effect is more pronounced at lower speed and stand-off distance.

(3) Surface finish improves due to Plasma Hot Machining . Further improvement is obtained as the stand-off distance is decreased.

(4) Surface hardening takes place due to Plasma Hot Machining. Mircohardness increases by 8% during Plasma Hot Machining compared to Conventional Machining at 52 m/min.

(5) Torch should be kept as close to the work piece as possible .

(6) Even though the results show the trends in the behaviour of various parameters, to achieve maximum benefit, torch of higher capacity should be used.

4.2 Scope for Future Work

(i) The observed effects in the present study can be studied with torch of higher capacity and lower cutting speeds for different HSTR materials .

(ii) Residual stresses developed due to Plasma Hot Machining can be studied .

(iii) Metallographic analysis of the machined surface can be made.

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